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THE JOURNAL OF THE SOCIETY OF AUTOMOTIVE ENGINEERS

JUNE 1921

SOCIETY OF AUTOMOTIVE ENGINEERS INC.
29 WEST 39TH STREET NEW YORK

REALIZING the lack of scientific engineering data concerning the design, installation and maintenance of plain bearings, we have established a technical bureau, fully staffed and equipped to carry on experiments and tests for the purpose of assisting manufacturers in the proper use of plain bearings.

* * *

This bureau will study machine-design in its relation to bearings and will advise in their selection and design, their installation, lubrication and maintenance.

* * *

Manufacturers using plain bearings are urged to submit their bearing problems to us for careful, impartial consideration.

AMERICAN BRONZE CORPORATION

PLAIN BEARING ENGINEERS AND MANUFACTURERS OF NON-GRAN BEARING BRONZE

THE UNIVERSAL NON-GRAN BEARING BRONZE

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Non-Gran is a metal possessing distinct and exclusive friction resisting properties, which result from its physical qualities, rather than its chemical composition.

Non-Gran is composed of 86 parts copper, 11 parts tin and 2 parts zinc, plus the fractional parts necessary to total 100.

This formula approximates that of bronze, but microscopic examination shows that Non-Gran has a very different and denser molecular structure.

THE JOURNAL OF THE SOCIETY OF AUTOMOTIVE ENGINEERS

Vol. VIII June, 1921 No. 6

The Summer Meeting

THE Summer Meeting of 1921 at West Baden, May 24 to 28, was a distinct success according to the sentiments voiced by a large majority of the 700 members and guests in attendance. Weather conditions were not exactly ideal, but in spite of the handicaps resulting from postponement of sports contests, due to rain, the outdoor program was completed and everyone seemed to have their anticipated share in the fun. The facilities at West Baden lend themselves admirably to almost any weather and this fortunate condition, coupled with the arduous labors of the group of men in charge of the recreational features of the program, is responsible for the completion of the sports before the close of the meeting.

The extent and nature of the attendance were most gratifying to those who spent the spring arranging the many details of the meeting, which is a very diversified undertaking. All branches of the industry were represented and a great many of the faces have grown familiar by their periodical reappearance at the Society gatherings. For pure goodfellowship and congenial spirit it is difficult to find the equal of the Summer Meeting. The enthusiastic greetings and handshakes in the early stages of each annual summer get-together remind one of the atmosphere which prevails at college reunions. There is nothing more beneficial to an industry with problems to solve than the opportunity presented at assemblies of this character for mind-to-mind discussion of the obstacles to be overcome, whether they be engineering, commercial or financial. The industry's belief in this fact is best evidenced by the undiminished support of the 1921 Summer Meeting when economic conditions were not all that might have been desired.

THE ATRIUM OF THE HOTEL DURING THE CLOCK-GOLF CONTEST

SPORTS AND RECREATION

The sports program was the most popular feature of the meeting, as in past summers. The direction of the several contests was ably handled by Howard A. Coffin, who deserves unusual credit for his untiring efforts and enthusiasm. Mr. Coffin had the work well organized in groups, each of which was directed by one of his assistants. The golf tournament which Earl Roberts conducted in commendable style, seemed the most popular of the tournaments. Except for the rainy period on Wednesday and Thursday, the course was crowded with the followers of the mashie, putter and niblick. There were 99 contenders for the Society championship in the qualifying round. On Thursday the field narrowed down to 16 and in the finals on Saturday morning John Watson carried off the honors with Thomas Doe as runner-up. A flag tournament was played on Friday for those who failed to qualify for the championship flight. This was won by E. A. Ross.

The putting contest was won by J. E. Schipper. There were so many ladies interested in golf at this summer's meeting that a very exciting match was arranged for them by the committee. This was won by Miss Roberta Large, with Mrs. Jack Gray runner-up. Mrs. H. G. Jackson outdistanced the other ladies in the driving contest and won that event.

The singles and doubles tennis tournament was conducted by Stanley E. Bates. Second to golf in number of participants, but not in enthusiasm, this tournament had 32 entries in the singles and 12 teams in the doubles, the largest field recorded at a Summer Meeting. The doubles tournament furnished many spirited matches, Stanley E. Bates and W. J. Buettner winning the finals from H. M. Crane and C. F. Clarkson. The singles championship was not decided until Saturday afternoon, when C. F. Clarkson defeated W. J. Buettner (6-1, 6-1). Unfortunately the weather eliminated all chance of playing the Inter-Section baseball series, which had been laid out by Geo. H. Hunt, but a game was arranged for Friday afternoon to console those diamond artists who had spent weeks training for the anticipated fray. The

appropriate names, Gasolines and Kerosenes, were given the two nines, the latter showing the highest brake mean effective pressure in the ratio of 12 to 2. The personnel was as follows:

Kerosenes		*Gasolines*
L. C. Hill	Pitcher	J. G. Vincent
F. G. Whittington	Catcher	J. L. Carey
V. E. Clark	1st base	R. G. Bradley
L. P. Jones	2nd base	G. A. Christopher
K. M. Lane	3rd base	B. W. Brodt
George Hunt	Shortstop	George Sevale
V. Tomlinson	Left field	W. E. Dolan
J. C. Ferguson	Right field	Robert Wilson
Mortimer Frankel	Center field	Herbert Saurer

The trophies for the indoor and the outdoor baseball Section championships will necessarily be retained by their present holders until 1922, when it is hoped that J. Pluvius will show a better spirit of cooperation.

The setting for the races and field events was most picturesque, everyone not busy in the golf tournament or trapshooting gathering in the stand enclosing the athletic field to view the engineer athletes in action. All of the events provided exciting finishes and the humorous antics of the participants in the several stunt races kept the crowd thoroughly amused. The outstanding feature of the field day, at least in point of applause, was the ladies' baseball throwing contest in which the Misses Norma and Ruth Porter outdistanced all competitors and even made it difficult for the judges to return their throws.

In addition to the members of the Sports Committee, the following assisted in making the field day a success: B. G. Koether, head judge of track events; Mark Smith, head judge of field events; J. J. O'Neill, C. R. Bissel, clerks of the course, and C. B. Veal, starter.

W. H. Pratt shouldered the responsibility of the bowling and quoits events and succeeded in conducting several very interesting contests. Mr. Pratt showed the greatest skill in ringing the peg and won the men's quoits, 15-6 and 15-12, from W. L. McGrath. Mrs. Lon Smith won the ladies' quoits from Mrs. Howard A. Coffin, 11-3 and 11-4. In the men's bowling tournament F. J. Richardson carried off first honors, F. A. Clawson was second and H. F. Sauer third. Mrs. T. Milton won the ladies' bowling contest from Mrs. A. H. Bartsch.

The ladies had plenty of diversion provided for them during the hours when the members were busy in the technical meetings. Howard Spohn officiated as director of the card parties, in addition to acting as announcer and chairman of the dance committee. Three five-hundred parties were played, the first prizes being won by Mrs. George Goddard, Mrs. H. R. McMahon and Mrs. Frank B. Ruoff. In the two bridge parties Mrs. H. L. Horning and Mrs. F. S. Slocum proved most expert and won the first prizes. The ladies' indoor putting-contest in the center of the great atrium of the hotel proved to be one of the prettiest settings of the meeting. Some 200 of the folks were seated in a great circle, in the center of which the clock-golf course had been laid out. It was truly an impressive picture. Mrs. H. L. Horning won this event with the excellent score of 18, although closely pressed by Mrs. H. R. McMahon, with a 19. Mrs. H. G. Jackson took third after playing off a tie with Mrs. David Beecroft. The outdoor clock-golf was won by Mrs. H. A. Coffin, with Mrs. A. J. Poole, Mrs. Geo. A. Kraus and Mrs. David Beecroft placed second, third and fourth, respectively.

The croquet excited the usual interest among the ladies and after several closely contested matches Mrs. V. E. Clark won the singles and Mrs. Howard A. Coffin and Mrs. H. T. Ewald the doubles.

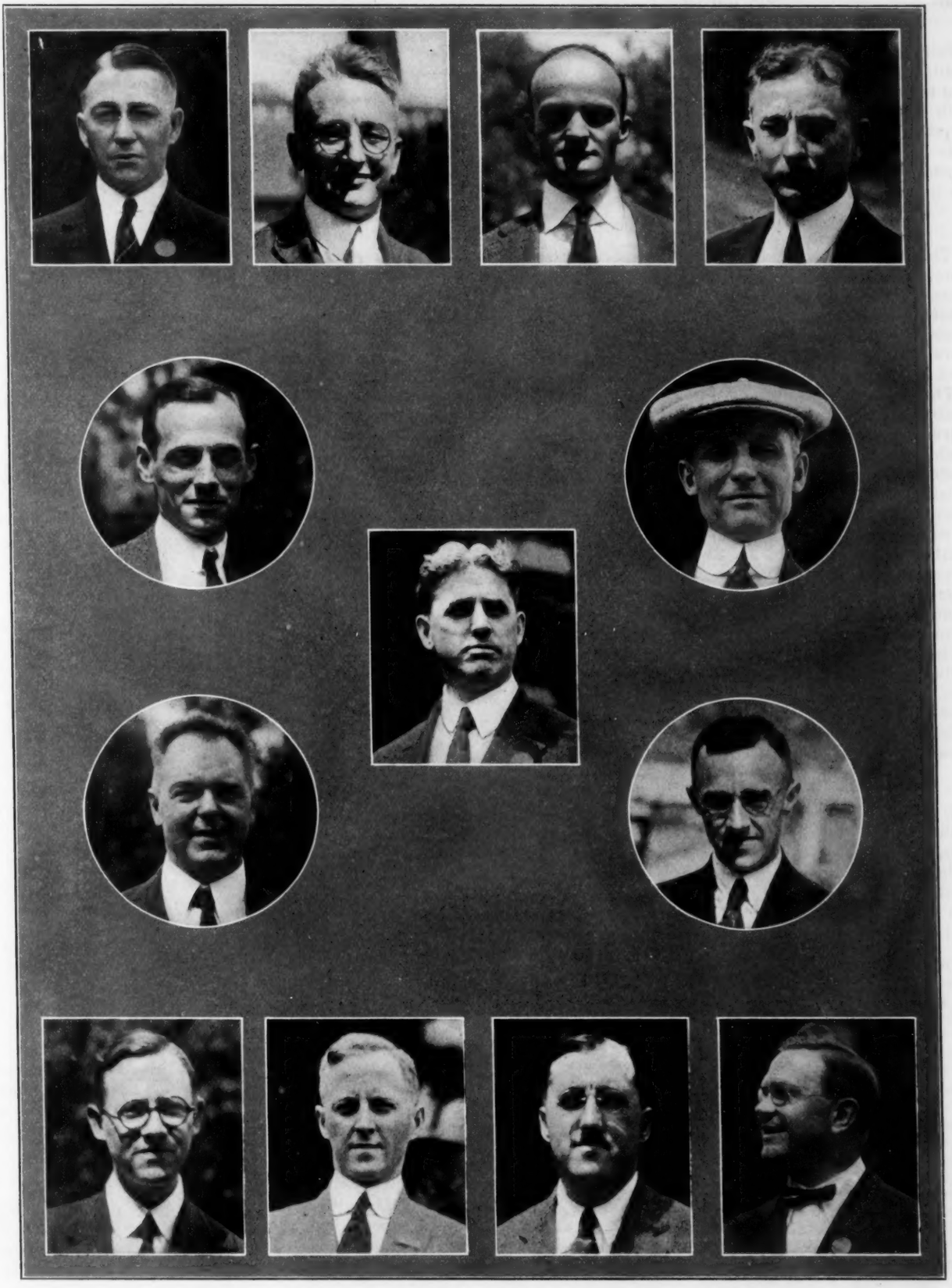
The trapshooting contest, arranged and conducted by Lon R. Smith, proved to be the one in which the greatest skill was demonstrated by the engineer athletes and sportsmen. When four shoots are won in four days with the high man breaking 49 out of 50 pigeons, it certainly is a noteworthy accomplishment. The sharp-shooters who set this unusual pace are J. A. Fesler, D. F. Fesler and W. H. Miller. In the finals for the Society championship, J. A. Fesler repeated his performance in the preliminary shoots and won with 49 out of a possible 50.

To describe the spacious and beautiful atrium each evening with its many soft lights, twirling dancers and brilliant, colorful settings is beyond accomplishment. The medley of frivolity, laughter and music will long rest in the memory of those fortunate enough to witness the extraordinary scenes. No other phase of the meeting excited greater comment. Seldom have the ladies of the Society danced to music so rhythmic, soft and pleasing. We know that next year's meeting will present a large attendance of the gentler sex, for everyone seemed to be so thoroughly pleased every hour of the day. The dance contest attracted many graceful entrants and it was a most difficult task to select the one entitled to first prize. Miss Estelle Brion, who had won the contest twice previously, was awarded the cup with a very narrow margin over Miss Roberta Large, who received second prize. The prizes for all of the athletic contests were awarded just after the dance contest by Chairman Howard A. Coffin.

Motion pictures were shown each evening in the atrium, a variety being selected which was certain to suit the tastes of everyone. The production of gasoline and other petroleum products was illustrated in a most instructive manner by a six-reel film, presented through the courtesy of the Associated Oil Co. Stephen S. Johnson gave a very entertaining lecture on the natural beauties of some of the national parks in the West.

The customary Section stunts were received most enthusiastically by somewhat skeptical audiences. Dr. Einstein, in the person of C. T. Myers, explained in detail the inner sphere of the popular hydrocarbons, with the assistance of M. C. Horine and C. R. Bissel, who manipulated uncanny apparatus and agitated colorful chemicals to illustrate the novel theories fostered by the Metropolitan Section. The Dayton Section built up an atmosphere of mystery around a helicopter which it had intended to fly but before the members had an opportunity to view the gyrations, the Section put on a private exhibition for the West Baden natives, thus spoiling the party. The Cleveland crowd decided to center their efforts in the circus ring, and the reception which greeted their free peanuts, freaks, clowns and acrobats indicated that the audience was more than pleased. L. L. Williams deserves honorable mention for creating this diminutive Ringling show.

Indiana night was the most elaborate entertainment provided by the Sections, for Indiana was anxious to impress those outside her borders with the hospitaltiy of the Hoosier State. Appropriate noise-makers, balloons and paper hats were distributed before the dinner to add the carnival touch. Thomas Taggart spoke briefly, and the Hoosier poet, Bill Hershell, entertained with tales and verse. Richard Lieber, of the Indiana Conservation Bureau, gave an excellent address. The real hit of the



AUTHORS OF PAPERS AND SOCIETY OFFICERS

C. W. Stratford W. E. Lay W. S. James G. P. Dorris
B. B. Bachman J. G. Vincent
David Beecroft
C. F. Clarkson C. F. Scott
Herbert Chase F. C. Ziesenheim H. L. Horning V. E. Clark

affair, however, was Mark Smith who impersonated an Italian officer and presented a most interesting engineering talk on nothing in particular. Some who were present still deplore the discourtesy accorded the foreign guest by those who realized that the presentation was a hoax. Lon Smith, B. F. Kelly and all others of Indiana who arranged this enjoyable evening are to be congratulated on its success.

Standards Committee Reports

The reports submitted by 10 Divisions of the Standards Committee included 25 subjects with reference to which recommendations had been formulated since the Annual Meeting of the Society held in January. Nineteen of the recommendations were accepted as submitted, while four were approved in amended form and two were referred back to the Divisions.

The two recommendations referred back related to ball studs, reported by the Engine Division, and rating of storage batteries, submitted by the Isolated Electric Lighting Plant Division. The report of the latter was made in two sections, referring respectively to the cancellation of the present standard and the substitution therefor of a new method of rating batteries for service in connection with isolated electric lighting and power plants. The first section of the report was approved, but it was thought that the second section should be reconsidered by the division and farm light and powerplant manufacturers with a view to bringing about greater harmony of opinion concerning a suitable standard.

The division report, as accepted by the Standards Committee and approved at the Council and the Society meetings, will be published in complete detail in the July issue of THE JOURNAL for the purpose of taking a letter ballot on their adoption, all of the full members of the Society being entitled to vote.

Nomination of 1922 Officers

B. B. Bachman was nominated to serve as President of the Society for the next calendar year by the Nominating Committee, which was completed and organized at the West Baden meeting. The committee reported the following other consenting nominees for the elective offices next falling vacant under the constitution, i.e., after the 1922 Annual Meeting of the Society:

First Vice-President—J. V. Whitbeck
Second Vice-President, representing motor-car engineering—F. E. Watts
Second Vice-President, representing tractor engineering—O. W. Young
Second Vice-President, representing aeronautic engineering—V. E. Clark
Second Vice-President, representing marine engineering—H. E. Morton
Second Vice-President, representing stationary internal-combustion engineering—C. B. Segner
Councilors (to serve during 1922 and 1923)—H. M. Crane, Lon R. Smith and C. F. Scott
Councilor (to serve during 1922)—W. R. Strickland
Treasurer—C. B. Whittelsey

The members of the 1921 Council who will hold over during 1922, are David Beecroft as past-president and Councilors W. A. Brush and F. W. Davis.

The Nominating Committee was constituted of F. M. Germane (chairman), Pennsylvania Section; L. W. Rosenthal, Boston Section; H. R. Corse, Buffalo Section; A. E. Jackman, Cleveland Section; Thomas Midgley, Jr., Dayton Section; Russell Huff, Detroit Section; H. W. Slauson, Metropolitan Section; Foree Bain, Mid-West Section; A. W. Scarratt, Minneapolis Section; Dr. H. C. Dickinson, Washington Section; G. P. Dorris, R. E. Northway and E. A. Sperry, members at large, and M. A. Smith (secretary), Indiana Section. This was the annual Nominating Committee, provided for by the Society's constitution, under which 20 or more members entitled to vote may constitute themselves a special Nominating Committee, with the same power as the Annual Nominating Committee. The by-laws of the Society provide that a special Nominating Committee, if organized, shall on or before Nov. 15 present to the Secretary of the Society the names of the candidates nominated by it for the elective offices next falling vacant, together with the written consent of each.

Presidential Address

President Beecroft delivered in an eloquent manner an address on current domestic and foreign automotive trade conditions and on the proposed work of the Research Department of the society. He stated with emphasis that no time could be more appropriate than the present for the commencement of such work. He pointed out at some length the fundamental value of and necessity for intensive research and dissemination of new and old facts in proper form.

Treasurer's Report

The report of the treasurer showed that the total assets of the society were $207,522.44 on April 30, 1921, with accounts payable of $9,377.23; that the income of the society for the first seven months of the present fiscal year had been $6,137.44 in excess of the expenses for the same period, and that a comparison of income and expense for the first six months of the present fiscal year with the corresponding figures for last year indicated very little change in the total figures, which was considered to be very gratifying in view of current industrial conditions.

Membership Growth

The Membership Committee reported that 324 applications for membership had been received during the first four months of this calendar year; the corresponding figures for 1920 being 406. The number enrolled on the roster of the Society on April 30, 1920, and April 30, 1921, were 4798 and 5468 respectively.

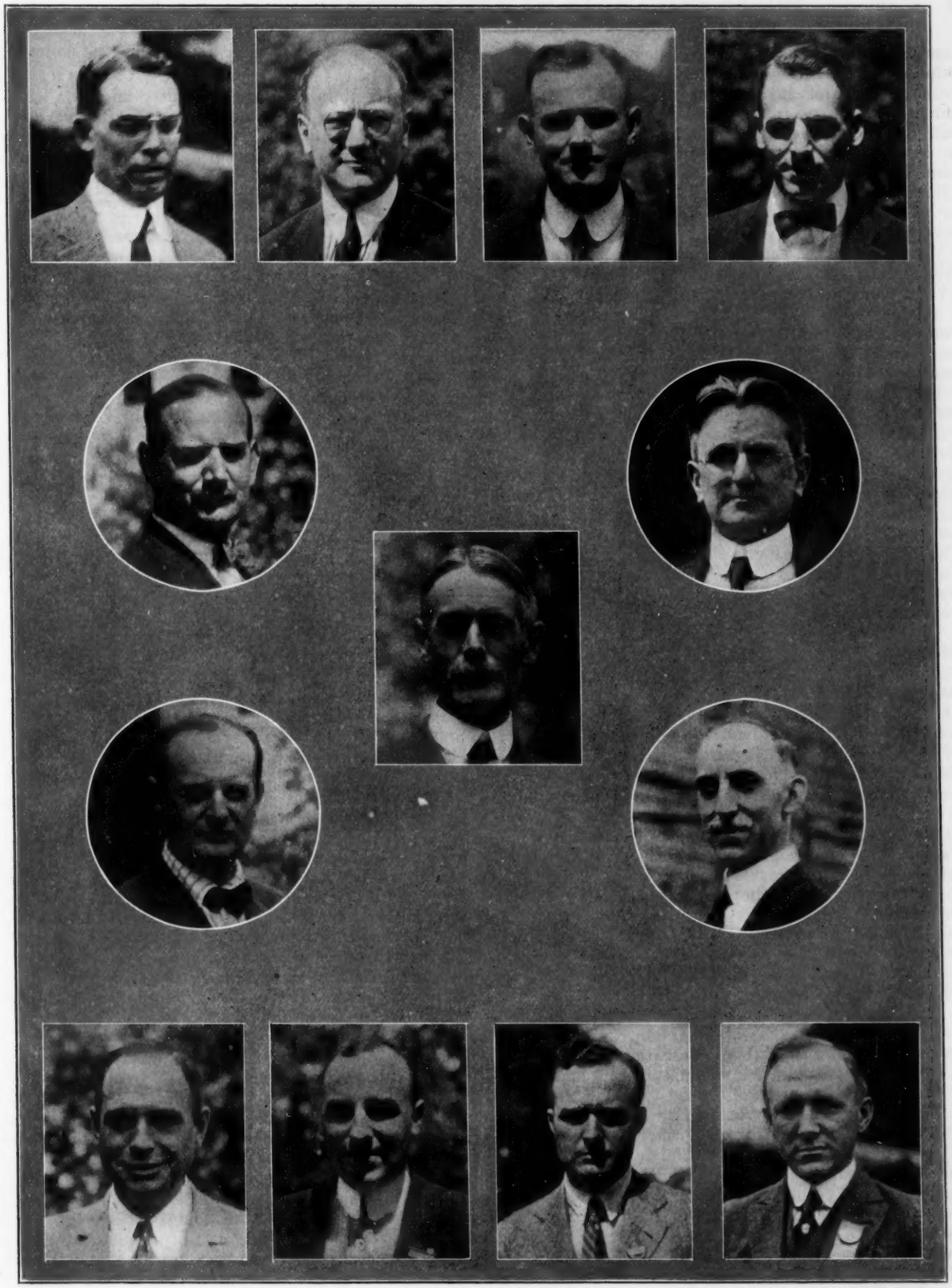
The Sections

The Sections Committee submitted a report on the increased membership in and greater value of the work of the sections. The committee met the council and a large number of the sections' officers at luncheon and discussed plans for the future. It is believed that much good will result from this meeting.

Technical Sessions

Many favorable comments were heard on the character of the papers presented at the technical sessions. The general impression seemed to prevail that the subjects covered were presented in admirable fashion and in a manner beneficial to all of those who took an interest in this phase of the meeting. The discussions were generally terse and pertinent, and the chairmen in charge of the sessions should be commended for the manner in which they were conducted.

The paper by L. E. Pierce and G. J. Mead on Aviation



AMONG THOSE WHO TOOK A PROMINENT PART IN THE MEETING WERE

W. G. Wall F. M. Germane O. C. Berry H. C. Buffington
Alfred Reeves M. L. Heminway
H. M. Crane
H. R. Corse H. C. Dickinson
E. A. Johnston Robert Wilson Thomas Midgley, Jr. A. W. Scarratt

Powerplant Development aroused much interesting discussion. Mr. Pierce, who read the paper, stressed the necessity of better installations of the powerplant to eliminate the engine failures in the air which generally result from minor defects in the operation of the gasoline, cooling or lubrication systems, independent of the engine itself. A very interesting discussion was given by Elmer Sperry, who urged the study of the Diesel engine as a possible powerplant for the airplane of the future, particularly in view of its burning a fuel whose low volatility reduced the fire hazard. The present status of commercial air transportation was discussed frankly by V. E. Clark in his paper on Air Transportation and the Business Man. This paper was welcomed by the members as representing one of the most candid expositions ever given of the obstacles which are at present impeding the progress of commercial aviation. It was felt that discussions of this sort would prove most constructive in the foundation of commercial aviation on a sound economic basis. Mr. Clark mentioned the need for Federal control for commercial aviation in his paper, and this subject was discussed very thoroughly by S. H. Philbin, who presented the matter from a legal standpoint. J. G. Vincent presided at the aeronautic session and contributed considerable discussion.

The matter of transport engineering education was discussed in a paper by C. J. Tilden, which was read by Alfred Reeves. Mr. Tilden emphasized the need of providing a proper curriculum in our universities in order that men could be given an education which would fit them for the practical management of motor-transport companies. A. T. Goldbeck of the Bureau of Public Roads stressed the need for better cooperation between the highway engineer, who builds and maintains the nation's roads, and the automotive engineer, who designs most of the vehicles which use them. Mr. Goldbeck believed that it would eventually become necessary for the automotive engineer to lessen the weight concentrated on each individual wheel by increasing the number of wheels in large motor trucks used for highway transport. At the same time he recognized the responsibility of the highway engineer for improving the design of highways to carry the larger loads imposed upon them by modern motor trucks. Mr. Goldbeck suggested that the Society appoint a responsible committee of automotive engineers to cooperate with the Association of State Highway Officials and it was voted that this be acted on by the President of the Society.

H. M. Crane, chairman of the Research Committee, presided at the general research session. The paper by L. A. Hawkins on Industrial Research was read by title. C. W. Stratford gave a very interesting and educational talk on the subject of lubrication and discussed some of the research study on lubrication problems that has been done under his direction on the Pacific coast. The paper by Herbert Chase on Clutch Design aroused considerable interest, and Mr. Chase was commended by the members for gathering together such a quantity of valuable design data and information. The members expressed the hope that similar papers would be prepared in the future on other major units of the motor car. W. E. Lay described the plan recently inaugurated at the University of Michigan to place the laboratory and personnel facilities of the university at the disposal of industrial organizations to further promote advanced research study.

The Combustion Research Session produced three extremely valuable papers. Judging from the reception accorded it, H. L. Horning's paper on Turbulence seemed to be one of the most important of the week. The advantages of maintaining a turbulent mixture in the combustion-chamber of an automotive engine were enumerated by Mr. Horning. Forms of combustion-chambers which tended to produce turbulence in the charge were shown and the improvement in engineering performance resulting from this turbulence set forth. C. A. French presented a hypothesis on the action of flame and combustion in internal-combustion engines. This produced active discussion on the part of the members, much of which will prove of value in the further study of flame phenomena. An abstract of Sir Dugald Clerk's paper on Cylinder Actions in Gas and Gasoline Engines was read in very able fashion by Prof. Daniel Roesch. It was to be regretted that illness prevented the attendance of Sir Dugald Clerk in person, for the members had looked forward to the occasion of his being with us at the Summer Meeting. The paper outlined in a comprehensive manner the life study of the internal-combustion engine which has been made by the author and it will serve as an excellent reference work for those engineers who are interested in the fundamental thermodynamic theory of the present-day automotive engine. Thomas Midgley, Jr., made a capable chairman for this meeting, particularly in view of his personal achievements in the study of combustion problems.

The discussion during the Fuel Research Session was probably more active than that had in any other session. This session was directed by O. C. Berry, who has spent considerable time in the study of carburetion and the fuel problem. The possibility of developing a Diesel or high-compression type of engine for adaption to automotive apparatus was discussed thoroughly in the paper presented by F. C. Ziesenheim. Mr. Ziesenheim's analysis of the fuel problem led him to the conclusion that this type of engine should receive careful study as one of the determinant factors in deferring the fuel shortage. George P. Dorris described a manifold developed on somewhat new lines for the purpose of trapping and distilling over the higher ends of modern engine fuels, thus preventing their entering the combustion-chamber in liquid form and either passing out of the exhaust unburned or draining into the crankcase and diluting the lubricating oil. A very comprehensive paper, enumerating in detail the many elements affecting automotive fuel economy, was presented by W. S. James of the Bureau of Standards. Appendices were contributed by Dr. H. C. Dickinson, S. W. Sparrow, and by R. L. Wales. This paper was intended as more of a summation of the work that has been done on the fuel problem than as a presentation of any new theories or experiments. Dr. Dickinson's appendix on Detonation was particularly commended by the audience. In the discussion following the presentation of the paper, Prof. Robert Wilson of the Massachusetts Institute of Technology described the method he has used in determining the dew-point of gasoline. He also illustrated with slides the value of these data to the engineer who is troubled with manifold and carburetion problems. Thomas Midgley, Jr., informed the members of the recent discovery of a fuel dope or alternative which was much more effective in eliminating fuel knock than any used previously. Due to the effectiveness of this material, only a small percentage need be added to the fuel, and Mr. Midgley felt that this would eventually lead to higher compressions in Otto-cycle engines and enable them to attain thermal efficiencies comparable to those of the Diesel engine.

Cylinder Actions in Gas and Gasoline Engines

By Sir Dugald Clerk[1]

Semi-Annual Meeting Paper *Illustrated with* Charts and Drawings

I HAVE read the excellent papers of A. L. Nelson[2] and Thomas Midgley, Jr.[3] and that of C. A. Woodbury,[4] H. A. Lewis and A. T. Canby with much interest and approval. I have gathered from them that you are experiencing the same difficulties with regard to oil fuel in America as we are in England. I agree with the authors of the last paper that it is necessary to turn attention to using other fuels such as kerosene, benzol and alcohol, and also to increase the engine efficiency when using the existing standard fuel.

You have been good enough to invite me to read a paper before you on the actions within the cylinder of a gasoline engine; hence the title chosen by me. My experimental work has been mostly performed on gas engines of relatively large cylinder-diameter, but many observers have found the same phenomena in gasoline engine work. I have also experimented with many gasoline engines, but it is much easier to study diagrams and flame effects with the slower-running gas engine.

I shall begin with a short account of the principal actions common to all internal-combustion engines, and then proceed to a more detailed account of the experiments which have been made to develop the theory and establish the properties of the flame working fluid of those engines.

Short Statement of Cylinder Actions

During the suction stroke of the ordinary four-stroke internal-combustion engine, the charge of air and gas or air and gasoline vapor and spray flows through the valve opening at a velocity which usually exceeds 100 ft. per sec. or 68 m.p.h. It enters the cylinder and fills it with a mixture of the fresh charge and the exhaust gas remaining from the last power stroke, all in a state of violent agitation or eddying. This agitation dies down in time, but at the end of the compression stroke, just before ignition, there remains a considerable internal motion. In a gas engine of 9-in. cylinder diameter and 17-in. stroke tested by me I found the residual turbulence at that point sufficient to increase the velocity of the spread of the flame after ignition to three times that which occurs in a still mixture of the same composition. As this state depends on the piston speed, an increase of the piston speed causes an increase of the initial turbulence, and hence a more rapid spread of flame to meet the increased rate of piston movement. Without this automatic change of ignition rate the high-piston-speed gasoline engine would have been impossible.

During the suction stroke the mixed charge passes through the valve opening at the temperature of the atmosphere, in the case of the gas engine, but somewhat below it in the usual case of the gasoline engine, due to evaporation of the liquid fuel; and as the valves and piston-end and cylinder walls are hotter than the charge, heat flows into it, and whenever the charge is complete its temperature is raised in a gas engine to about 100 deg. cent. (212 deg. fahr.), partly because of the heat-flow into the charge and partly because the cool charge is mixed with a certain proportion of hot exhaust-gases at the beginning of the suction stroke, whose temperature is about 500 deg. cent. (932 deg. fahr.)

This mixture at the suction temperature of 100 deg. cent. (212 deg. fahr.), when compressed in the engine mentioned which has a 5.5 compression-ratio, rises to about 360 deg. cent. (680 deg. fahr.) at a pressure of about 120 lb. per sq. in. above atmosphere. On ignition the temperature rises to a maximum of 1600 deg. cent. (2912 deg. fahr.) in about 1/40 sec., and the maximum corresponding pressure becomes about 330 lb. per sq. in. above atmosphere at nearly 1/20 of the forward stroke. The speed of this engine is 200 r.p.m., so that one revolution takes 0.30 sec. and a single stroke 0.15 sec. Had turbulence been absent at the time of ignition it would have required nearly 0.1 sec. to complete the spread of the flame and the maximum temperature would not have been attained till half stroke forward.

The time of inflammation necessary for a gasoline engine running at 1200 r.p.m. is much shorter; at this speed it should not exceed 1/120 sec., and at higher speeds much greater rapidity is required to give reasonable efficiency. The late Dr. W. Watson gave 1/300 sec. as the time in a small gasoline engine tested by him. Assuming the flame to travel 4 in. to fill the small cylinder, then its velocity must be 100 ft. per sec.

The flame velocity in an engine varies with the suction velocity and also with the gaseous or liquid fuel employed. Thus in one large cylinder gas engine of 22-in. diameter and 34-in. stroke, running at 160 r.p.m., the explosion period with Mond gas, suction gas and coal gas was respectively 1/21, 1/24, and 1/38 sec., and the corresponding flame velocity 47, 54 and 85 ft. per sec. The inlet velocity was 160 ft. per sec. In a smaller gas engine the inlet velocity was 100 ft. per sec. and the flame velocity 37 ft. per sec. With the richest mixtures used in gas and gasoline engines the flame temperature rises as a maximum value to 2000 deg. cent. (3632 deg. fahr.), although one set of experiments made by Professors Dalby and Callendar reached 2400 deg. cent. (4352 deg. fahr.). In both gas and gasoline engines the rate of flame transmission with turbulence varies from 30 to 100 ft. per sec.

When the spark ignition is placed in the center of the combustion space open to the piston without pockets, the ignition starts as a small hemisphere and spreads for-

[1] Past-President, Institution of Automobile Engineers.

[2] Fuel Problem in Relation to Engineering Viewpoint, published in The Journal, February, 1921, p. 101.

[3] Combustion of Fuels in Internal-Combustion Engines, published in The Journal, December, 1920, p. 489.

[4] Nature of Flame Movement in a Closed Cylinder, published in The Journal, March, 1921, p. 209.

ward and outward in all directions; the flame-front travels somewhat slowly and compresses the mixture in front of it toward the cylinder walls and the piston. The mixture is thus submitted to further heating by compression before the mass of it is ignited. As the flame continues to spread, the portion first ignited near the spark-plug is subject to compression also, so that as the hemisphere expands compression proceeds on both sides of the flame boundary, the hot gases at first passing forward into the mixture as in expanding at constant pressure, and later hot gases flow back from the flame-front as well as forward, so that the flame nearest the igniter sustains the longest period of compression and is heated above the temperature of explosion by nearly adiabatic compression. This recompression is important, as it emphasizes the necessity for thorough cooling of the spark-plug so as to avoid overheating and preignition. The late Professor Hopkinson discovered this interesting temperature-rise in 1906 by experiments made with optical indicator and platinum wire thermometer by means of a large explosion vessel. Turbulence modifies the action, but it must occur in all usual designs of gas and gasoline engines. When the flame passes through the whole combustion space and reaches the walls, the temperature at the spark-plug end may be as high as 500 deg. cent. (932 deg. fahr.) above the temperature at the walls, notwithstanding that this part is the last ignited and has lost but little heat. When the flame reaches the enclosing walls and every part is filled with flame, the combustion is not yet complete. In some gaseous explosions the flame fills the whole space before the pressure completes its rise. This was inferred by me in 1885 from gaseous explosion experiments made with my first explosion apparatus, but it was definitely proved to be the case by Hopkinson's experiments in 1906 mentioned above. Hopkinson found that 85 per cent of the total pressure-rise had occurred when the flame filled the vessel, but 15 per cent further rise completed the explosion period.

In Hopkinson's experiments with a mixture composed of 1 part gas and 9 parts air, the rate of flame propagation was about 6 ft. per sec. During the pressure-rise due to the spread of the flame, heat loss from the flame at once begins, because of radiation, and the radiation increases with the general temperature-rise; conduction and convection also then act, so that when maximum mean-temperature is attained, a portion of the heat of the explosion has already passed to the cylinder walls and water-jacket. This portion was much underestimated by the earlier experimenters. On this important subject Hopkinson, with his pupil David, now Professor David, of the University College of Cardiff, made ingenious experiments in closed vessels with a metal strip calorimeter and a bolometer, measuring the radiation passing through a fluorite window to the instrument. Radiation was shown to have a most important effect.

David has experimented with mixtures of coal gas and air in a closed vessel of about 12-in. diameter and 12-in. length. Three mixtures were used; 15, 12.4 and 9.7 per cent by volume of gas. At the moment of maximum temperature of the explosion he found the distribution of the energy of combustion of the gas present to be as given in Table 1.

TABLE 1—DISTRIBUTION OF THE ENERGY OF GASEOUS EXPLOSIONS AT THE MOMENT OF MAXIMUM TEMPERATURE

Coal Gas in Mixture, per cent	Heat of Combustion, units	Internal Thermal Energy, per cent	Available Chemical Energy, per cent	Heat Loss to Walls of Vessel, per cent
15.0	100	81.0	10.0	9.0
12.4	100	78.0	12.0	10.0
9.7	100	72.5	9.5	18.0

The most economical mixture used in gas engines is about 10 per cent. Assume that mixture to be used in the cylinder we are considering and suppose the losses to be similar to David's losses in still mixture. In that case, when our cylinder has been filled with flame at the highest mean temperature and pressure, the loss from radiation and convection during the explosion period will be 18.0 per cent and there will be 72.5 per cent available as thermal energy, together with 10.0 per cent of heat still to be evolved by chemical action. That is, we have altogether 82.5 per cent of the original total heat of combustion available during the expansion period. Assume that the expansion proceeds during a complete power-stroke; then, in an ordinary gas engine, work is done on the piston and heat is lost to the enclosing walls and temperature falls. The work done and the heat lost by the gases is greatest in the first 30 per cent of the stroke. At the end of the stroke the mean gas-temperature has fallen, when the jacket is hot and the engine has been working at full load, to about 900 to 1100 deg. cent. (1652 to 2012 deg. fahr.). The exhaust-valve then opens and the pressure quickly drops to atmospheric or near it. A considerable portion of the heat of the exhaust gases passes into the water-jacket, so that the temperature and calorimeter measurements of the gases in the exhaust-pipe after leaving the engine give lower temperatures and heat quantities than those proper to the exhaust-gas mass at the end of expansion. During the exhaust stroke the hot gases in the cylinder give up a portion of their heat to the water-jacket. Because of the two losses after expansion the water-jacket temperature-rise does not give a true indication of the heat distribution during explosion and expansion. The friction of the piston in the cylinder, which is the largest mechanical loss in the running of the engine, also generates heat, which passes away partly by the piston and water-jacket, so that from many causes the jacket gets more heat than that due to the thermodynamic action of the engine.

In making running tests under full load it is necessary to allow for all these matters to arrive at a true balance-sheet of heat-disposal by the engine. Even when such a balance-sheet is prepared it is necessary to know the properties of the flame working fluid as to specific heat at various temperatures, the change of volume during combustion and radiation from the engine itself, as well as high-temperature radiation to the cylinder walls from the flame. To know the margin still available for improvement in thermal efficiency it is necessary to determine the maximum efficiency possible, assuming all operations to be perfectly performed without loss of heat in any part of the cycle. For this purpose many valuable investigations were carried out by the late Prof. Bertram Hopkinson and the late Prof. W. Watson. Both men were brilliant and indefatigable experimenters. Professor Hopkinson was in charge of designing and testing new types of airplanes during the war, and our science suffered a sad loss when he was killed when flying from Martlesham Heath Airdrome to London in August 1918. Prof. W. Watson was in charge of poison-gas defence operations in France, and he also died in 1918 as the result of the hardships experienced during the war. His loss was a great blow to the science of the internal-combustion engine. The other English investigators are Professors Callendar, Coker, Dalby, Dixon, Petavel and

Gibson, Mr. Ricardo and Dugald Clerk. These men worked together beginning with the year 1907 as members of the Gaseous Explosions Committee of the British Association, of which I am the present chairman.

Investigations have been made in France by MM. Mallard and Le Chatelier and M. Berthelot and Prof. Aime Witz. Holborn & Henning and Professors Meyer and Junker have made interesting tests in Germany. In America valuable explosion experiments have been made at the Massachusetts Institute of Technology with coal gas and gasoline and air mixtures. The late Prof. R. H. Thurston made important tests and studies of the Brayton petroleum engine and the early Otto engines. Prof. R. C. Carpenter, too, did valuable work in this connection.

As I have devoted much attention also to the limits of thermal efficiency possible in internal-combustion engines I shall, first, discuss rapidly our present efficiencies and knowledge and, secondly, deal with the problems presented by heavier liquid fuels.

The Air Standard

The air standard was first used to compare the thermal efficiencies of internal-combustion engines in a paper[5] read by me in London in 1882. I then proved that in a compression gas engine expanding to the same volume after ignition as before compression and igniting at constant volume the efficiency is determined by atmospheric absolute temperature, and the absolute temperature after compression, and I pointed out that the efficiency is independent of the rise of temperature above the temperature of compression. Whatever be this temperature-rise the proportion of heat converted into work remains the same.

In a book on The Gas Engine published in 1886 I carried the thermodynamic discussion further and deduced the equation for thermal efficiency in terms of compression ratio as

$$E = 1 - (V_c/V_o)\,\gamma - 1$$

where

V_o = the volume in the cylinder before compression
V_c = the volume in the cylinder after adiabatic compression

As now used it is put in the form

$$E = 1 - (1/r)\,\gamma - 1$$

where

$1/r$ = the compression-ratio

The air-standard efficiencies corresponding to values of 0.50 to 0.01 for $1/r$ with heat added at constant volume and expanded to the volume existing before compression are given in Table 2.

TABLE 2—AIR-STANDARD EFFICIENCIES FOR COMPRESSION ENGINES

$1/r$	E
1/2	0.246
1/3	0.360
1/4	0.430
1/5	0.480
1/6	0.510
1/7	0.550
1/10	0.610
1/12	0.630
1/18	0.680
1/20	0.700
1/100	0.850

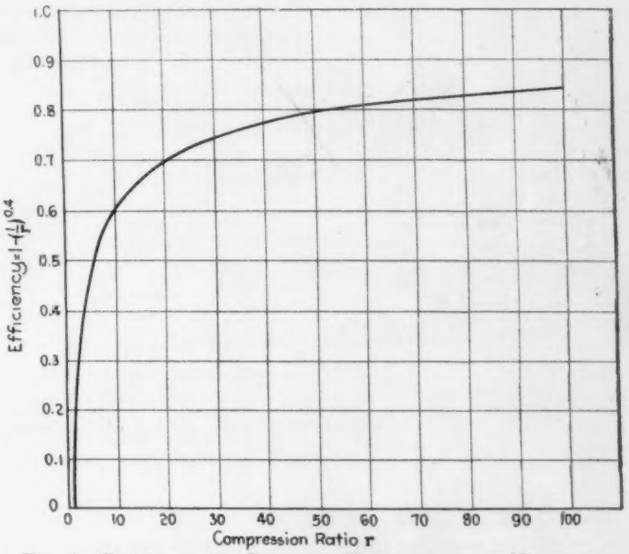


FIG. 1—CURVES OF AIR-STANDARD EFFICIENCIES FOR DIFFERENT COMPRESSION RATIOS

The Institution of Civil Engineers adopted this standard on Dec. 19, 1905, as the result of the investigations of a Committee on Efficiency of Internal-Combustion Engines. The Committee included Professors Unwin, Kennedy and Callendar, and they made tests of three engines of 5.5, 9 and 14-in. diameter cylinders respectively, with practically identical compression-ratios of 1/5.5 approximately, to find the relationship between the air-standard and the actual efficiencies.

The results obtained by dividing the indicated thermal efficiency by the air-standard efficiency were 0.61 for the engine with the 5.5-in. cylinders, 0.65 for the 9-in. and 0.69 for the 14-in.

The engines gave respectively 6, 24 and 60 i.hp. From this it appeared that for a small engine 0.61 of the air-standard value gave the practical result of an engine, allowing for heat losses, while the large engine developing 10 times the power lost less heat and gave 0.69 of the air standard. As the result of many tests it can be accepted that in practice if we calculate the maximum indicated thermal efficiency from the corresponding ratio of the air standard, 0.6 can be taken as the minimum and 0.7 the maximum. Fig. 1 gives curves of air-standard efficiencies from ½ to 1/100 and practical results can be deduced by multiplying by 0.7 and 0.6.

Flame the Actual Working Fluid

It was known in 1905 that the specific heats of the products of combustion are higher than that of air and that they increase with rise of temperature, but the specific heat values were very uncertain. Accordingly I set to work with the largest engine of the Committee and determined the specific heat of the flame in the working cylinder by a new method depending on alternate compression and expansion of the flame within the cylinder. The experiments and calculations occupied two years, and in March 1906 I read a paper[6] at the Royal Society of London giving my results. From the data so determined I prepared a paper for the Institution of Civil Engineers.[7] I then came to the conclusion that in actual operation the 14-in. cylinder engine converted into indicated work 88 per cent of the heat which it possibly

[5] The Theory of the Gas Engine, read before a meeting of the Institution of Civil Engineers held April 4, 1882, and published in the *Proceedings*, vol. 69, p. 220.

[6] The Specific Heat of Heat-Flow from and Other Phenomena of the Working Fluid in the Cylinder of the Internal-Combustion Engine, published in the *Proceedings of the Royal Society*, vol. 77, p. 500.

[7] The Limits of Thermal Efficiency in Internal-Combustion Engines, published in the *Proceedings of the Institution of Civil Engineers*, vol. 169, p. 121.

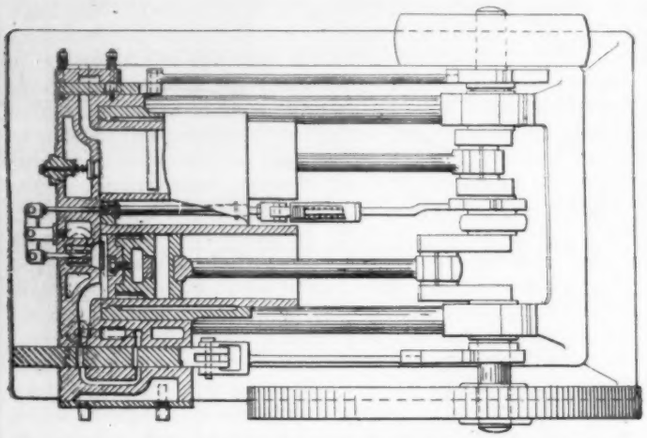


FIG. 2—PLAN VIEW PARTLY IN SECTION OF A TWO-STROKE ENGINE BUILT IN 1878 AND 1879

could have converted into work, considering the properties of the working fluid, as compared with air. Complete suppression of all heat loss would only add 12 per cent to the indicated thermal efficiency of this engine; the value would be 39.5 instead of 34.7 per cent.

The air standard, although most useful in giving comparative results at different ratios of compression, must not be used for reasoning on the possible limits. Thus, the relative efficiency of 0.7, that is, 70 per cent, implies that if the air standard could be attained 30 per cent would be added, while the real value proves to be 12 per cent. It follows from this that the margin of possible improvement on the best results obtained at full load is not great. Little is to be hoped from improvements in reducing heat-flow to the cylinder walls; contrary to what many engineers and inventors believe, the heat loss from the flame to the water-jacket is of little importance from the economy point of view in the best of existing engines.

The results I have given were obtained with a relatively large gas-engine cylinder, but the tests made on the best gasoline engines now show equally good values. Thus, H. Ricardo has shown that gasoline engines operating at 1600 r.p.m., with overhead valves opening directly into the cylinder which was 7.25 in. in diameter with an 8.50-in. stroke, readily give an indicated thermal efficiency of 33 per cent and this value is about 0.7 of the air standard and about 88 per cent of the actual working-fluid standard. Mr. Ricardo has designed and built a special single-cylinder gasoline engine arranged so as to permit of altering the compression-ratio while the engine is running. He has published in Table 3 the maximum indicated thermal efficiency obtained at values of 1/4, 1/5 and 1/7 respectively for $1/r$. To enable this wide compression range to be attained he used benzol. Mr. Ricardo followed me in giving an approximate formula for the actual working-fluid efficiency at different compression. I proposed the use of a value of 1.285 for γ for the particular working fluid of the gas engine; for the products of combustion of benzol and gasoline Mr. Ricardo uses 1.295.

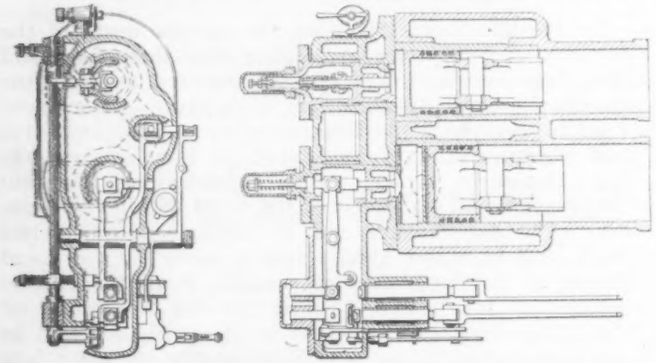


FIG. 3—VIEW OF THE TWO-STROKE ENGINE BUILT BY DUGALD CLERK IN 1886

TABLE 3 — VARYING COMPRESSION-RATIO EXPERIMENTS USING BENZOL

Compression-Ratio	Maximum Indicated Thermal Efficiency Calculated $E=1-(1/r)^{0.296}$	Maximum Indicated Thermal Efficiency Observed	Ratio of Observed to Calculated Thermal Efficiency	Air-Cycle Efficiency	Ratio of Observed Thermal Efficiency to Air-Cycle Efficiency
1/4	0.337	0.277	0.82	0.425	0.650
1/5	0.380	0.316	0.83	0.475	0.665
1/7	0.440	0.372	0.85	0.540	0.685

The change from ¼ to 1/7 compression-ratio raises the indicated thermal efficiency from 27.7 to 37.2 per cent; that is, only 74.5 per cent of the fuel used at the low compression is required to produce the same power at the higher, and the ratio between no heat loss and practice rises from 82 to 85 per cent. The mechanical efficiency also rises, so that the saving is well worth making. The air-cycle ratio varies from 0.650 to 0.685, practically 0.7, the same as with the gas engine.

If all fuels had properties similar to benzol, it would be possible to get these high efficiencies by simple redesigning, but some fuels "knock" badly under compression-ratios with which others work quietly. This knocking is a great difficulty, which is as yet only partly understood. All we know positively is that high compression-ratios produce knock; why, it is difficult to say.

KNOCKING, PINKING, DETONATING

The knock is a very old enemy. All the early inventors are familiar with it, especially those of us who devoted ourselves to two-stroke engines. I began my work on

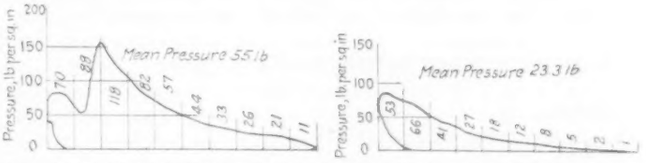


FIG. 4—DIAGRAMS FROM THE PUMP AND ENGINE CYLINDERS OF THE ENGINE SHOWN IN FIG. 3

internal-combustion engines at the end of 1876. I invented, designed and built my first two-stroke engine in 1877, and first exhibited it at work in public at the Kilburn Show of the Royal Agricultural Society in 1879. Fig. 2 is a sectional plan of this engine which had two cylinders, each of 6-in. diameter and 8-in. stroke; one was the pump and the other the engine cylinder. The pump crank followed the engine crank at right angles, and it pumped a mixture of gas and air into an intermediate reservoir through a check-valve. From this reservoir the mixture was supplied to the engine cylinder by a slide-valve. The reservoir pressure was 70 lb. gage. The engine piston moved back to the end of the cylinder, leaving only sufficient mechanical clearance. The exhaust-valve was closed early to cushion the piston. The engine piston moved forward about 2 in. of its stroke, taking in the compressed mixture from the reservoir; the slide-valve cut off the supply and caused ignition by an incandescent platinum cage carried in the slide. The engine gave 4 b.hp. at 300 r.p.m. It knocked bady with

rich mixture; even with weak mixtures of coal gas and air the knock could still be heard.

A larger engine was built with a cylinder 10 in. in diameter and an 18-in. stroke, which knocked so badly that the blow could be felt in the ground outside the building about 100 ft. away, and was heard also at long distances. The knock was overcome by altering the point of ignition, removing it from the admission port. Water spray, too, was injected into the cylinder at full load. A modified engine of this type was built in 1886. A sectional plan view is given in Fig. 3 and Fig. 4 shows diagrams from the two cylinders. This engine knocked less than the other, but could be caused to knock badly by keeping the compression admission-valve open to the engine cylinder too close to the ignition point.

Fig. 5 shows diagrams from the engine and pump cylinders of another type of two-stroke compression engine. Fig. 6 shows an original diagram from engine and pump cylinder. The combustion space was formed between two pistons which balanced each other, and the pistons moved together to perform all the required valve actions. The engine knocked badly under all conditions of running, as is evident from the engine diagram shown in Fig. 6.

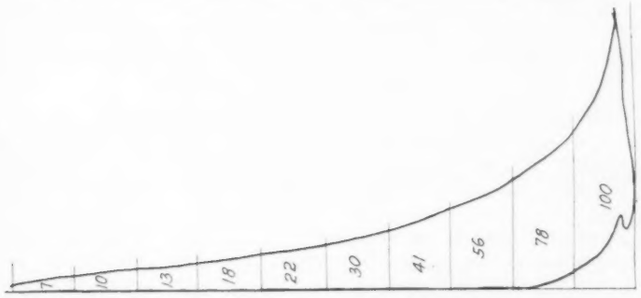


FIG. 5—DIAGRAM FROM THE ENGINE CYLINDER OF A TWO-STROKE COMPRESSION ENGINE

The three types of engine all knocked badly, and at the time it was difficult to understand why. All the engines had one feature in common; the gas mixture was forced into the combustion space and the last portion was injected at high velocity under compression-pressure from the pump through the rapidly closing ports or passage of the charging valve. The mixture was undoubtedly agitated violently at the last moment previous to ignition. Accordingly the pressure-rise was so rapid as to cause great shock. Non-compression engines, such as the Lenoir and the Bischoff, also give a violent knock. Fig. 7 is a sectional elevation of the Bischoff non-compression engine. Air and gas is drawn into the cylinder from the atmosphere and gas supply pipe through an automatic inlet-valve, and ignition is caused by the piston overrunning a small port having a check-valve and sucking in a portion of a flame burning outside. This engine gives a violent shock with a rich mixture. The shock obtained with rich mixtures of coal gas and air in those early days was very violent; there was no doubt about it. Mr. Midgley's graphic description of the sulphuric-ether knock applies accurately to the worst knocking.

> The curve rises smoothly along compression but, shortly after ignition, something happens. This is the knock, the noise of which can be heard across a 10-acre lot

The first engine designed and built by me which was quite free from knock was produced in 1880 at Glasgow and patented in 1881. It is the engine best known by my name, and is used in thousands for small and large

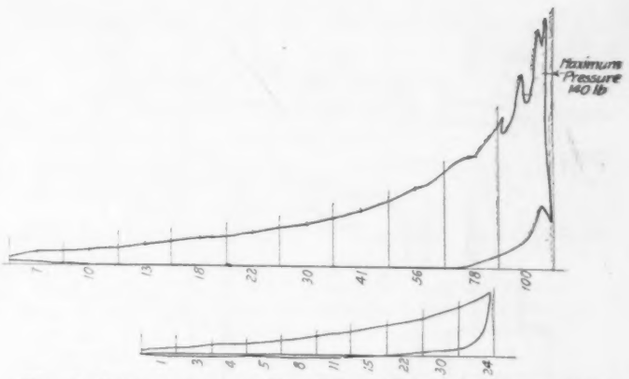


FIG. 6—DIAGRAM FROM A TWO-STROKE ENGINE BUILT IN 1885 SHOWING THE EFFECT OF KNOCK ON THE EXPANSION

power-units. A sectional plan view and elevation are shown in Fig. 8, and the diagram of an engine of 9-in. cylinder diameter and 20-in. stroke is reproduced in Fig. 9. The explosion was perfectly smooth in these engines; no knock was experienced under any circumstances. The ignition, as I now know, was rather slow, because the design of the pump and the engine minimized possible turbulence. Compression-pressures of 60 lb. above atmospheric pressure were considered high in 1881, and at these pressures knock difficulties did not appear. The experiments with compression-ratios as high as 5 to 6 in gas engines and the natural wish to get higher mean effective pressures by using richer mixtures produced conditions in experimental engines of four-stroke type which again produced the knock in a milder form. At the same time the use of gasoline under high compres-

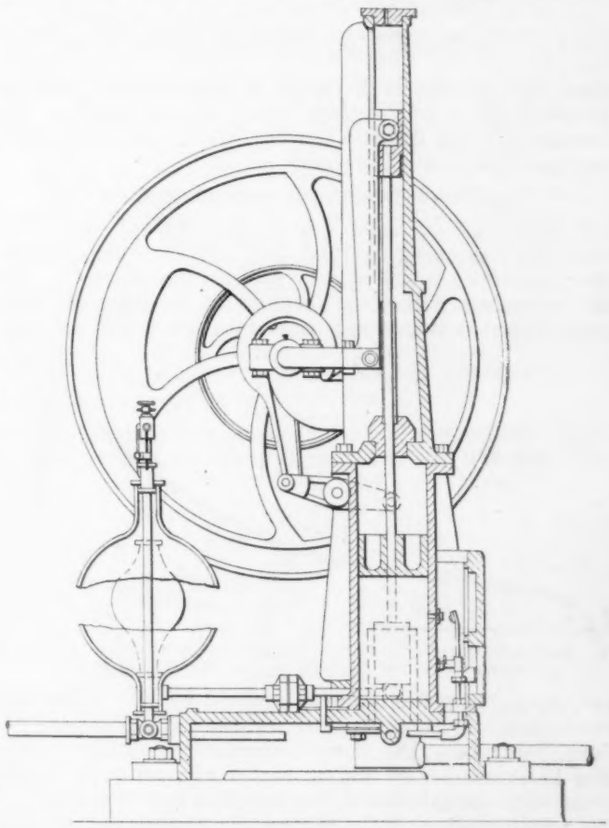


FIG. 7—SECTIONAL ELEVATION OF THE BISCHOFF NON-COMPRESSION ENGINE BUILT IN 1880

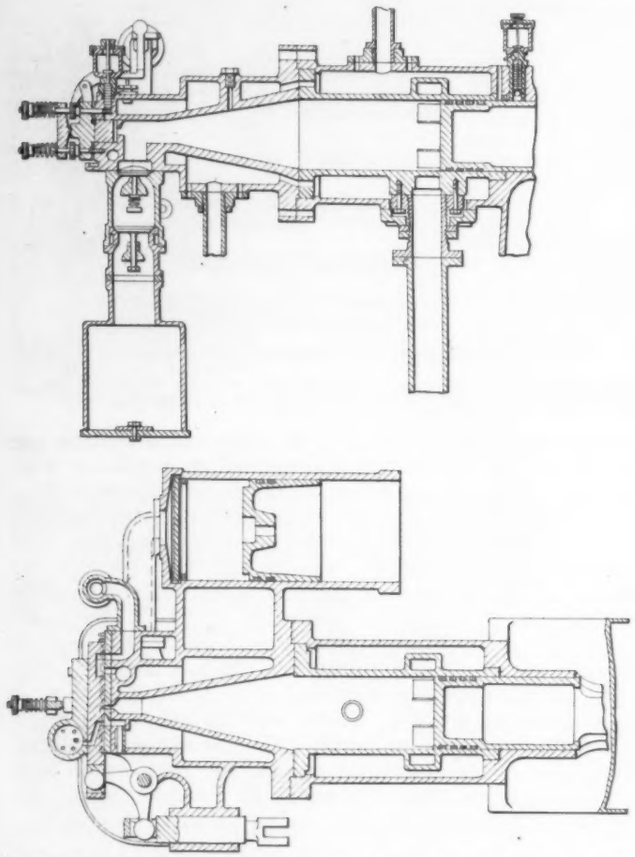


FIG. 8—SECTIONAL ELEVATION (ABOVE) AND PLAN VIEW (BELOW) OF A TWO-STROKE COMPRESSION ENGINE BUILT IN 1881

sions and paraffin or kerosene at lower ratios produced knocking of a very severe type. Water-injection was adopted by some firms to control this in exactly the same way as I had controlled knock in 1880.

AIR AND EXHAUST SUPERCOMPRESSION

I experimented upon four-stroke engines with rich mixtures beginning in 1902, and applied supercompression by added air and also by cooled exhaust-gases. The air supercompression had been tried by Daimler many years before but had not come into use. The exhaust-

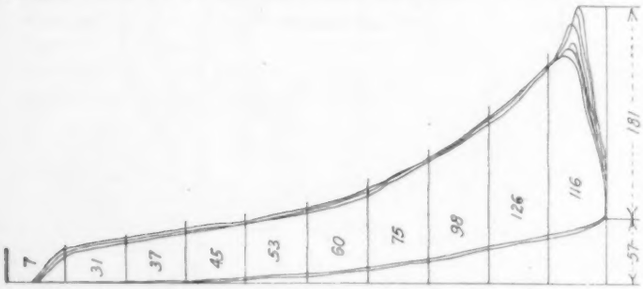


FIG. 9—DIAGRAM FROM A 12-HP. ENGINE BUILT IN 1881 HAVING A CYLINDER DIAMETER OF 9 IN. AND A STROKE OF 20 IN.

gas supercompression was originated by me. The idea was to use strong gas and air-charges at high compressions, controlling the flame temperatures, which would then be excessive, by adding cooled exhaust-gases under pressure to the cylinder at the charging end of the stroke. The total pressure of the charge was thus raised by 3 to 5 lb. above that of the atmosphere before the compression began. The total weight of working-fluid per cylinder-charge was thus increased by from 20 to 25 per cent, and so the flame temperature was reduced. At the same time the mean available pressure was increased. The proportion of carbonic acid gas in the exhaust, too, prevented preignition and also knocking. Fig. 10 is an indicator-card showing two superposed diagrams, one without and the other with exhaust supercompression. The sharp peaked diagram with the lower compression is that without exhaust-gas supercompression. The flattened-top diagram with the higher compression has been produced by exhaust supercompression, and its effective area is greater than the other. The ordinary diagram is ap-

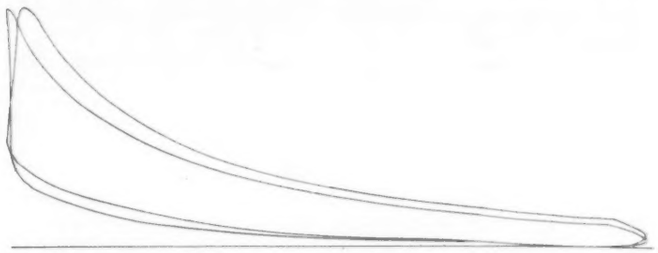


FIG. 10—INDICATOR SHOWING TWO SUPERIMPOSED DIAGRAMS, ONE WITH AND THE OTHER WITHOUT EXHAUST SUPERCOMPRESSION

proaching nearly to a knock; the other is beautifully smooth-running. In this experiment the gas-charge is identical for both types, and by moving a lever the engine is made to run on or off supercompression at will. In this experiment a plate was bolted to the end of the piston to increase the compression; the plate was very hot, and although the engine ran steadily, giving 28 b.hp. with exhaust supercompression, it preignited and pulled up when the supercompression charge was cut off, as shown on the diagram which is reproduced in Fig. 11. In this case the preignition was noiseless. Fig. 12 gives particu-

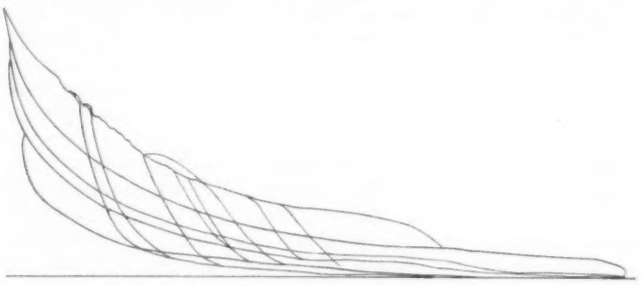


FIG. 11—DIAGRAM SHOWING PREIGNITION WHEN THE EXHAUST WAS SHUT OFF

lars of a test with supercompression and shows an engine diagram, while Fig. 13 is a light-spring diagram which demonstrates the action of the pressure exhaust-gases in filling up the cylinder at the end of its charging stroke.

I have also applied exhaust gases to prevent preignition in large gas engines when using coke-oven gas and to permit the compression-ratio to be increased without

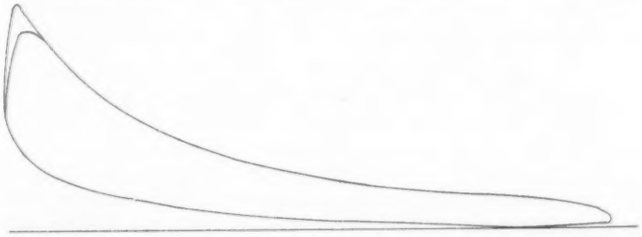


FIG. 12—EXHAUST SUPERCOMPRESSION DIAGRAM WITH THE ENGINE LOADED

knocking. The cylinders, 23 in. in diameter with a 24-in. stroke, were of the vertical tandem type, and a compression-ratio of 1/7 was attained with coke-oven gas, which is rich in hydrogen. At first the exhaust gas was cooled and taken into the engine cylinder with the air-charge; later it was drawn into the gas conduit and mixed with the gas to be supplied to the engine, the same proportion being used as in the first instance. The exhaust gas successfully deals with the use of rich gases in large engines. These vertical engines are built in sizes from 300 to 2000 b.hp. Small parafin or kerosene engines of high speed which knock badly when arranged in the ordinary way become practically silent when their exhaust gases are taken into the engine. In my opinion, you will find that your trouble from knock in kerosene engines will be solved by using a mixture of exhaust from the engine with the air entering the cylinder. I do not know to what compression-ratios you can carry the method.

Residual Turbulence

In the foregoing account of my experience on knocking I have not troubled you with theories but have confined myself to difficulties found in the course of many years' design and experiment. I am, of course, deeply interested in the theory of the working fluid and I am much gratified that American engineers are taking the great interest in abstract matters which is so evident from the many able papers presented before this Society.

I shall now deal with the theory of the working fluid but first I would say that my friend Mr. Wheeler has somewhat mistaken the nature of my discovery of suction turbulence. What I have discovered and proved definitely is, that the turbulence which we all know was created by the high velocity of the air and gas in entering the cylinder, persists during the compression stroke of the gas or gasoline engine to a sufficient extent to affect profoundly the rate of inflammation of the compressed mixture. This investigation was made by me in 1911. Long before that time I was fully aware that (*a*) turbulence existed in the engine cylinder during the admission of the charge through the inlet valve and passage and (*b*) that if turbulence be produced in a mixture of gas and air the inflammation of the charge proceeds more rapidly. With regard to the first point I made the following statement in my book The Gas Engine[8] in 1885 while discussing the question of stratification in the Otto engine cylinder:

> A little consideration of the arrangement of the Otto engine will show that stratification cannot have any existence in it. The end of the combustion space is usually flat, and sometimes the admission port projects slightly into it; the area of the admission port is about 1/30 of the piston area; accordingly the entering gases flow into the cylinder at a velocity 30 times the piston velocity, or at the Otto piston speed, about 120 m.p.h.
>
> Great commotion inevitably occurs; the entering jet projects itself through the gases right up against the piston, and then returns eddying and whirling till it mixes thoroughly with whatever may be in the cylinder. The mixture becomes practically homogeneous even before compression commences
>
> Experiments made by Dr. John Hopkinson and the author on full-size glass models of the Otto cylinder show this mixing action very beautifully

With regard to the second point, I made the following statement in my paper on The Theory of the Gas Engine,[9]

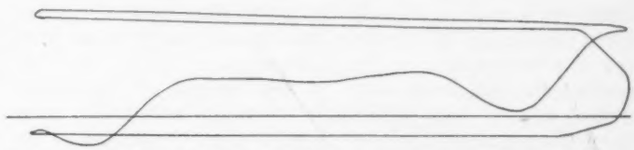


Fig. 13—Indicator Diagram Obtained with a Light Spring Showing the Action of the Pressure Exhaust Gases in Filling Up the Cylinder at the End of the Charging Stroke

read to the Institution of Civil Engineers in London on April 4, 1882:

> The author has found it possible to ignite a whole mass in any given time between the limits of 0.10 and 0.01 sec., by so arranging the plan of ignition that a small volume of gaseous mixture is first ignited, expanding and projecting a flame through a passage into the mass of inflammable mixture, and thus adding to the rate of ignition the mechanical disturbance produced by the entering flame. He has succeeded by this means in producing maximum pressure in 0.01 sec. in a space containing 200 cu. in. This rate of ignition is too rapid, and would not give the engine time to take up the slack in bearings, connecting-rods, etc. But by firing a mixture with varying amounts of mechanical disturbance almost any time of ignition can be obtained between 0.01 and 0.10 sec. It does not matter whether the mixture used is rich or weak in gas; the rich mixture can be fired slowly and the weak one rapidly, just as may be required. The rate of ignition of the strongest possible mixture is so slow that the time of attaining complete inflammation depends on the amount of mechanical disturbance permitted

Then followed diagrams which were taken from an early Otto engine and they were referred to as follows:

> A diagram from an Otto engine shows what happens in a compression engine of type 3 [type 3 was the engine in which heat was added and discharged at constant volume] when the ignition comes late and the movement of the piston overruns the rate of the spread of the flame. It is then seen that the maximum pressure is not attained until far on in the stroke, and as a consequence great loss of power results, the pressure attaining its maximum when it is time for the exhaust-valve to open. This may happen from several causes, a too diluted mixture, or too little mechanical disturbance by the entering flame; or the ignition may be missed until the pressure begins to fall by the forward movement of the piston, when the rate of inflammation begins to come more nearly to Mallard's number of 11 in. per sec. This slow combustion, or rather slow inflammation, is to be avoided in the gas engine. Every effort should be made to secure complete inflammation as soon after ignition as practicable

Notwithstanding my regular use of flame projection to increase mechanical disturbance when ignition was too

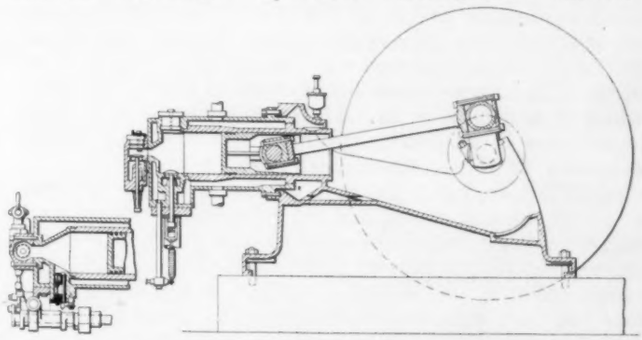


Fig. 14—Longitudinal Sectional Elevation and Partial Sectional Plan of the Gas Engine Used in Turbulence Experiments

[8] See The Gas Engine, pp. 255-6.

[9] See *Proceedings of the Institution of Civil Engineers*, vol. 69, p. 243.

slow, yet I entirely missed the point that residual turbulence remaining in a gas or gasoline-engine cylinder during the completion of the compression stroke was the really efficient accelerator of the spread of the flame which caused the difference between relatively slow flame-propagation in the closed-vessel experiments as compared with the engine cylinder. The experiments demonstrating this interesting point were made by me in 1911 and published in the Report of the Gaseous Explosion Committee of the British Association at its meeting at Dundee in 1912. Fig. 14 shows a longitudinal section and a part sectional plan of the gas engine used in the experiments. The cylinder was 9 in. in diameter and the stroke 17 in. It was the medium engine of the Institution of Civil Engineers Committee tests for air standard already referred to. Fig. 15 reproduces two of the diagrams taken; in the upper the back electric-ignition was used and in the lower the side ignition.

I had long before observed that gas engines would have been impracticable had the rates of explosion been the same in actual engine cylinders as in closed-vessel experiments. In an engine running at 150 r.p.m., the stroke takes 0.2 sec., so that it would be impossible to attain the maximum pressure till the end of the stroke with a time explosion of 0.2 sec. In an ordinary engine working at such a speed, maximum pressure is attained in from 1/20 to 1/30 sec. with a mixture of about 1 part of gas to 9 parts of air and exhaust gas; and no complete explanation of the greater rate was offered till 1911, when, in the course of some experiments, I found that the rate of explosion-rise in the same engine varied with the rate of revolution, increasing with increased number of rotations per minute, and was due to the turbulence or eddying caused by the rush of gases into the cylinder during the suction stroke, which persisted during the compression stroke. I was studying the effect of this suction turbulence on heat loss during the working stroke of a gas engine by drawing in a combustible charge into the cylinder in the ordinary way, and then tripping the valves and compressing and expanding this charge for one or two revolutions before firing. By this means turbulence was given time to die away, and it was expected that a comparison of an expansion-line obtained in this way with that following a normal ignition would show the effect of suction turbulence on heat loss. The experiments did not clearly indicate increased heat loss on the explosion and expansion-line, probably because of the relatively high radiation and convection losses at the particular temperatures used, but another interesting point was discovered which is of considerable importance in the practice of the internal-combustion engine in all its forms. It was at once found that the effect of damping-down turbulence was to retard the rate of inflammation or explosion to a remarkable extent, so that the nature of the indicator-diagrams was completely changed. Two of the diagrams so taken are reproduced in Fig. 15, from which it will be seen that suction turbulence is of vital importance in producing the high rate of inflammation necessary to secure economical working in all internal-combustion engines. In Fig. 15 the ordinary ignition a to b at the end of the first compression-stroke rises to maximum temperature of explosion in 0.037 and 0.033 sec. respectively; while the ignition a' to b' on the third compression of the piston, after the imflammable mixture has been compressed and expanded twice and then again compressed, takes respectively 0.092 and 0.078 sec. The mixture in both cases was 1 volume of gas and 9.3 volumes of air and other gases. The cylinder was kept hot, the jacket temperature being 70 deg. cent. (158 deg. fahr.), and the engine was run at 180 r.p.m. under full-load conditions. The engine had a 9-in. cylinder diameter and a 17-in. stroke. It was fitted with two electric igniters, as shown in Fig. 14, one operated in the charge inlet port at the back of the combustion-chamber, and the other at the side of the cylinder, close to the piston when it was at its full-in position. In the upper diagram of Fig. 15 the back electrical-igniter was used for both ignitions on the diagram, and in the lower the ignition was effected by the side igniter. It will be observed that the inflammation is more rapid in both normal and delayed ignition with the side igniter, but in both cases the time of inflammation without turbulence is about two and one-half times that of a normal ignition when the gases have some turbulent motion. In most gas and gasoline engines the mean velocity of charge-flow through the inlet-valve is at the rate of 100 ft. per sec., and flame carried at this rate would completely fill the combustion space of this engine in about 1/130 sec., as the distance from each igniter to the extreme wall-limit is about 9 in. The actual time taken for normal complete inflammation was respectively 1/27 and 1/30 sec., so that the rate of normal flame-propagation with turbulence was about $100 \div 4.5 = 22.25$ ft. per sec., while the rate with trapped ignition and turbulence nearly-died-down was about 8.9 ft. per sec. From this it appears that the effect of suction turbulence is to increase the rate of inflammation about 13 ft. per sec. in this particular engine running at 180 r.p.m. The rate of inflammation in Clerk's closed-vessel experiments with a similar mixture was about 4 ft. per sec., and in Bairstow and Alexander's corresponding experiments 2.5 ft. per sec. In a large vessel having a capacity of 6.2 cu. ft., with a similar mixture, Hopkinson found the rate of inflammation about 5 ft. per sec. The velocity of inflammation in an actual engine is thus from four to five times that found in a closed vessel by Clerk and Hopkinson, and nine times that found by Bairstow and Alexander. My experiments would suggest a residual turbulence-effect in this engine at the moment of explosion of about 20 ft. per sec.

The late Professor Hopkinson experimented on turbulence at the same time as myself, but he operated in a closed vessel and produced his turbulence by the rotation of a fan within the mixture. Hopkinson's apparatus consisted of a cylindrical vessel 12 in. in diameter and 12 in. long, which was lined with strip copper to measure the rate of heat loss by the increased electrical resistance of this strip. A small fan was mounted in the center of the vessel, and comparisons were made of the results of exploding the same mixture, with the fan at rest and in motion. The experiments showed a great increase of the speed of inflammation consequent on the motion of the gas. With a mixture of 1 part of gas and 9 parts of air by volume, the time from ignition to maximum pressure with the gas at rest was about 0.13 sec.; with the fan running at 2000 r.p.m. it was reduced to 0.03 sec., and at 4500 r.p.m. to 0.02 sec.

Hopkinson also arranged experiments to determine the turbulence in an engine of 7-in. cylinder diameter and 15-in. stroke, running at 240 r.p.m. and driven by an electric motor. The method used was to determine the rate of loss of heat from a platinum wire mounted in the combustion-chamber, the wire being heated by an electric current. Hopkinson states that within moderate limits of temperature the heat loss from such a wire is proportional to the temperature-difference between it and the surrounding gas. The ratio between heat-loss and

temperature-difference is a measure of the effective conductivity of the gas, and depends on its temperature, density and state of motion. If the first two factors are the same, the effective conductivity depends only on the state of motion, and can be taken as a measure of its amount. Measurements were made of effective conductivity at the top of compression, first with the valves working in the ordinary way and then with the valves closed so that the same charge of air was continually compressed and expanded and suction turbulence was absent. At 240 r.p.m. the conductivity of the compressed air was more than 60 per cent greater in the first case than in the second, and at 60 r.p.m. the difference was only about 20 per cent. The temperature and density of the gas were the same in both cases, so that the difference could be due only to motion.

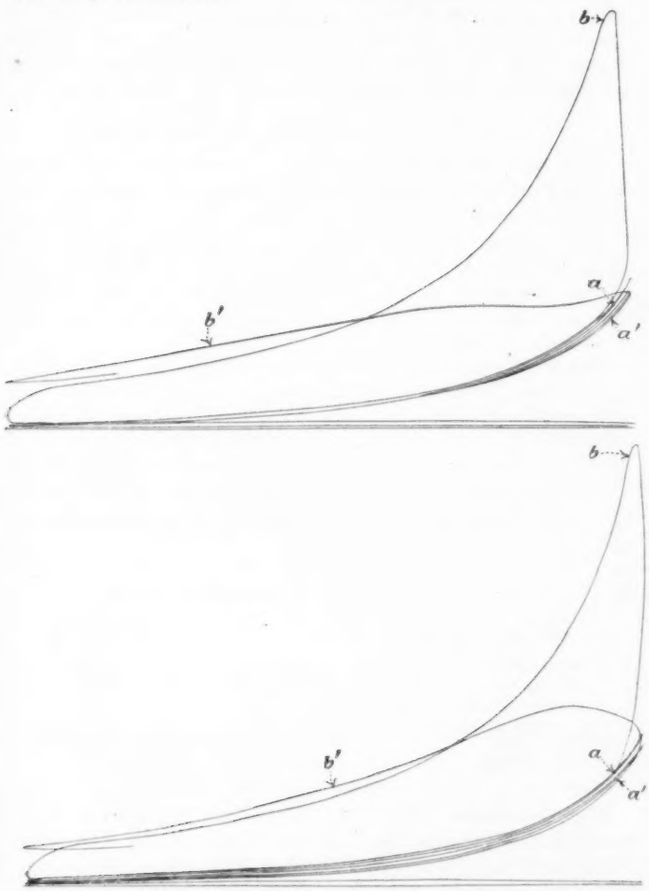


FIG. 15—TWO OF THE DIAGRAMS TAKEN IN CONNECTION WITH THE TURBULENCE EXPERIMENTS.
In the Upper the Back Electric Ignition was Used and in the Lower the Side Ignition

Hopkinson mounted a wire before a fan, and determined the air velocity which would produce a similar cooling effect on the wire, and from this experiment estimated the residual turbulence at the end of the ordinary compression-stroke.

It is to be remembered that the time of inflammation necessary for a motor-car gasoline engine is very much less than the 1/30 sec. which a gas engine requires. In gasoline engines running at 1200 r.p.m. the time of explosion should be about 1/120 sec., but at 2400 revolutions 1/240 sec. is necessary for efficiency. Dr. Watson

[10] The Explosion of Homogeneous Gaseous Mixtures, published in the *Proceedings of the Institution of Civil Engineers*, vol. 85, p. 1.

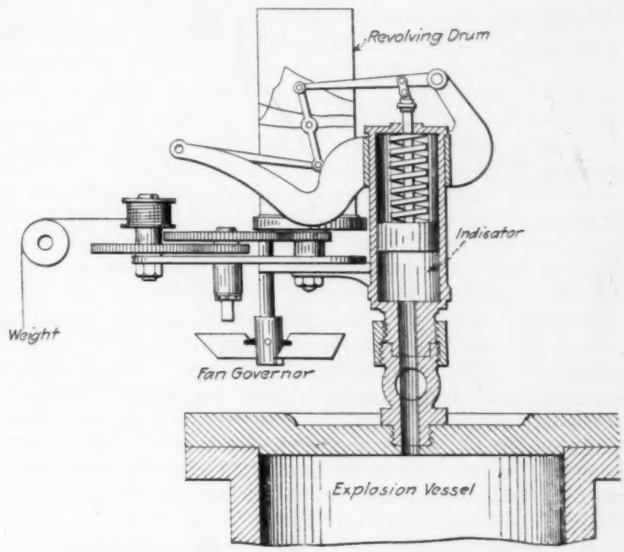


FIG. 16—EXPLOSION APPARATUS USED BY SIR DUGALD CLERK IN HIS EXPERIMENTAL STUDY OF GASEOUS EXPLOSIONS

gives 1/300 sec. as the time in a small gasoline engine. If the flame travels 4 in. to fill this small cylinder, its rate must be 100 ft. per sec., so that a high suction-velocity is necessary to ignite the contents in time to produce an effective stroke. From this it will be seen that the conditions of explosion are very different in closed vessels and actual engine experiments.

GASEOUS EXPLOSIONS

Before considering the other actions in the gas and gasoline-engine cylinder it is necessary to study the general and particular nature of gaseous explosions. I began my experimental study of gaseous explosions in 1884 and read my first paper[10] on the subject before the Institution of Civil Engineers in 1886. The apparatus used by me is shown in Fig. 16 and diagrams from mixtures of air with Glasgow coal-gas and Oldham coal-gas are reproduced in Fig. 17. Of these the most rapid rise to maximum pressure, 0.01 sec., is given by 2 volumes of hydrogen and 5 volumes of air. The most rapid rise with coal gas is 0.05 sec. with Glasgow gas but the time of the mixture commonly used containing 1/10 coal gas with both Glasgow and Oldham gases was 0.13 and 0.08 sec. respectively. In all cases mixtures at rest were used; turbulence was absent.

As a result of these experiments I came to the conclusion among other things that in some cases the whole explosion vessel was completely filled with flame before the maximum pressure was attained and that combustion

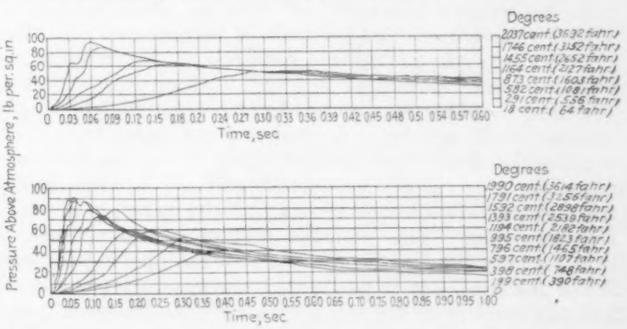


FIG. 17—TWO DIAGRAMS OBTAINED FROM MIXTURES OF AIR AND COAL GAS

continued for a considerable period after maximum pressure. I considered that the detonation of Berthelot which produced a speed of communication of chemical action in hydrogen and oxygen mixtures corresponding to 2 volumes of hydrogen and 1 volume of oxygen, of over 2000 meters per sec. (1.24 miles per sec.) did not exist in hydrogen or coal gas and air mixtures, although something approximating Berthelot's explosive-wave at a much lower velocity can be attained by the use of "a long and powerful spark" or by injecting a large flame from a small separate chamber. The maximum pressure of the explosion is, however, strictly limited and even detonation does not materially increase the maximum pressure. In this the gaseous explosion differs completely from the solid or liquid explosive. Detonation in gun-cotton or trinitrotoluol causes an almost indefinite pressure-increase. Thus Professor Hopkinson proved the pressure of detonating gun-cotton to rise as high as 100 tons per sq. in. No such change of pressure can occur with gaseous explosions; detonation but little exceeds the limit of ordinary inflammation.

It is easy, however, to arrange a gaseous explosion in such manner that the spread of the flame will compress in front of it by its movement a portion of the mixed charge through a check-valve or aperture so that a chamber is filled with mixture compressed above atmospheric pressure by the progress of the combustion. Thus it is easy to obtain explosion-pressures of 200 lb. per sq. in. above that of the atmosphere in a separate chamber instead of only 100 as in an ordinary gaseous explosion at atmosphere. I discovered this fact in 1891 and based on it the flame-starter for gas engines shown in Figs. 18 and 19. Fig. 18 is a diagrammatic section illustrating its action in which *a* is the gas-engine cylinder, *b* a check-valve opening into the exhaust-port, *d* and *c* a chamber connected by pipe *d* with the valve *b*, and *e* is an igniting-valve and *f* a port leading to a charging-pump. The object of the device is to fill the combustion space of the engine with a compressed mixture of gas and air, and then to explode the compressed mixture, thus starting the engine by a high-pressure explosion. To start, the crank is placed off the center; the pump is operated by hand to fill the chamber *c*, pipe *d*, and cylinder *a* with the gas and air mixture at atmospheric pressure, so that no resistance is experienced in operating the pump. The igniter *e* is then operated, and the mixture in the chamber *c* ignites near *e*; the flame, as it spreads through the chamber, forces the unburned mixture before it into the pipe *d*, through the valve *b* into the cylinder *a;* so that when the flame arrives at the valve *b*, it has swept before it into the cylinder all the unburned mixture. When the flame passes the valve *b* it ignites the compressed mixture in the cylinder; and, by producing a high-pressure explosion, the engine is started off with an ample margin of power to overcome the friction of belting and shafting.

In conjunction with F. W. Lanchester, I introduced the starting-gear reproduced in Fig. 19 which was known as the Clerk-Lanchester starter. In this arrangement a Lanchester igniting-valve *g* is used, and the pump for charging the chamber *h* is dispensed with. When the engine is stopping, the valve *i* is opened and air is thus pulled through the chamber *h* by way of the valve *g* at every suction-stroke. The chamber *h*, pipe *j* and cylinder *k* thus became filled with pure air at atmospheric pressure. When the engine is to be started, the gas-cock *l* is opened and gas flows from the main at *m* into the chamber *h* and at *n* into the pipe *j*, a cock on the cylinder is opened to allow flow into the cylinder or the exhaust-valve is held slightly open; the flame *o* burns across the valve *g*, and after a few seconds the mixture of gas and air escapes through *g* and burns in the air. The cock *l* is then closed and the flame shoots back past the valve *g*, and so ignites the mixture within *h*, thus closing the valve *g*. The flame proceeds along *h* and *j* into the cylinder *k*, firing the mixture it has compressed, and the engine is started by a compression explosion. Fig. 20 is a starting diagram obtained from this arrangement. From this it will be observed that a maximum pressure of over 200 lb. per sq. in., as well as a mean pressure of 74 lb. per sq. in., is easily attained as a starting explosion. These flame-starters were largely used for starting gas engines for several years. The principle is interesting as bearing on the theory of the rise of pressure in gaseous explosions, and in 1891 I pictured an ordinary gaseous explosion in an engine cylinder as a flame progressing through the mixture at a moderate rate with a fairly well defined flame-front, the flame compressing the unburned mixture adiabatically until ultimately it fills the whole vessel.

Flame Propagation and Recompression

The late Professor Hopkinson investigated this flame action in a large closed vessel of 6.2-cu. ft. capacity, 23.4 in. internal diameter and 28.75 in. long. The electric-spark ignition was central and a continuous record was taken of the variation in the resistance of fine platinum wires immersed in the gas, at different points; and at the same time and on the same revolving drum the pressure was recorded.

The experiments were made at the engineering laboratory of the University of Cambridge and Cambridge coal-gas was used. This gas had a calorific value at 760 mm. (29.92 in.) pressure and 0 deg. cent. (32 deg. fahr.) of 680 B.t.u. per cu. ft. and 1 cu. ft. required 5.76 cu. ft. of air for complete combustion. The analysis of the gas is given in Table 4, all values being in percentages by volume.

TABLE 4—ANALYSIS OF CAMBRIDGE COAL-GAS

Constituents	Percentage by Volume
Hydrogen	47.20
Methane	35.20
Heavy Hydrocarbons	4.80
Carbon Monoxide	7.15
Nitrogen	5.40
Other Gases	0.25

With 9 volumes of air to 1 of gas fired at atmospheric pressure a maximum pressure of 82 lb. per sq. in. above atmosphere was attained in about 0.25 sec. after firing, and it was found from the readings of the platinum-resistance thermometers that the flame spread roughly at the rate of 59 in. per sec. The spread of the flame differs slightly in different directions.

The flame reached the side-walls of the cylindrical vessel when the pressure was from 15 to 20 lb. per sq. in. above that of the atmosphere. At this point, however, only a small portion of the walls was in contact with the flame, that is the part nearest to the spark, and most of the gas mixture was still unignited. As the flame spread a greater and greater area of the walls came into contact with it, until it completely filled the vessel and was losing heat to every part of it. At this point the pressure had not attained its maximum, being about 70 lb. per sq. in., while the maximum reached was 82 lb. The maximum pressure was attained in less than 1/30 sec. after the flame completely filled the vessel.

The platinum thermometer at the center of the vessel shows that the temperature rises very rapidly after the moment of ignition, reaching 1225 deg. cent. (2237 deg. fahr.) in probably less than 1/50 sec., but that the thermometer rises very slowly until very near the point of maximum pressure. The platinum wire then suddenly melts, from which Professor Hopkinson deduced the temperature of the surrounding gases as 1900 deg. cent. (3452 deg. fahr.). This is the highest temperature attained by the explosion; all other points in the vessel are lower.

The distribution of temperature within this large vessel at the moment of maximum temperature is roughly as given in Table 5.

TABLE 5—DISTRIBUTION OF TEMPERATURE AT THE INSTANT OF MAXIMUM TEMPERATURE

Location	deg. cent.	deg. fahr.
Mean Temperature Inferred from Pressure	1,600	2,912
Center of Vessel	1,900	3,452
Point 4 In. from End Wall	1,700	3,092
Point 0.4 In. from End Wall	1,100 to 1,300	2,012 to 2,372
Point 0.4 In. from End Wall at Side	850	1,562

Professor Hopkinson's view was that at this moment little heat had been lost at the first three points and that the difference in temperature is almost wholly due to the

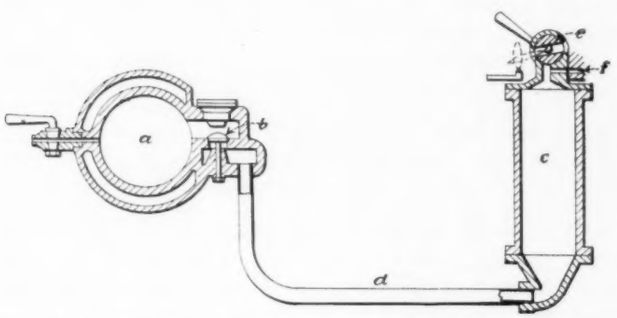


FIG. 18—DIAGRAMMATIC SECTION OF THE CLERK FLAME-PRESSURE STARTER

different treatment of the gas at the different places. At the center of the vessel it has been burnt at nearly atmospheric pressure and compressed after burning to about six and one-half atmospheres absolute, while at next to the last point in the table it has first been compressed to about six and one-half atmospheres as in a gas engine and then ignited with practically no subsequent compression. At the last point much heat has been lost since this is the first point reached by the flame; the gas here is ignited when the pressure is about two atmospheres, its temperature rises instantly to 1300 deg. cent. (2372 deg. fahr.) and at once begins to fall.

In these interesting and important experiments Professor Hopkinson demonstrated that when the vessel was completely filled the mean temperature had reached only 85 per cent of the maximum and that combustion was still proceeding although the whole cylinder was filled with flame. In my 1885 explosion experiments I had inferred this from the nature of the rising line due to spread of flame, but to Hopkinson belongs the great credit of proving experimentally by a platinum thermometer that this was the fact in the large vessel. Hopkinson discovered also the fact that the point of ignition is the

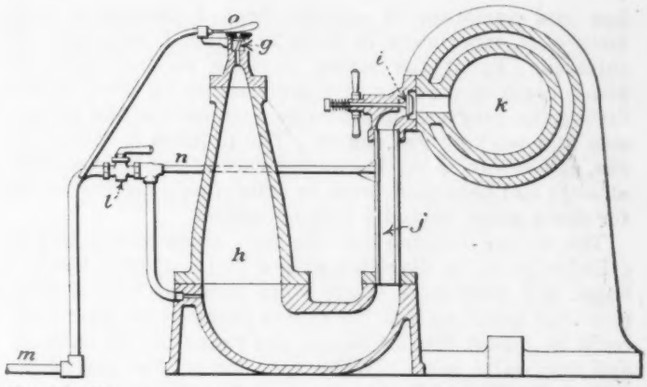


FIG. 19—DIAGRAMMATIC SECTION OF THE CLERK-LANCHESTER STARTER

point of highest temperature in a gaseous explosion and would be still the highest point even if no heat were lost to the walls. Had Hopkinson's vessel been truly spherical, then it would probably have been simpler in its temperature distribution at maximum temperature, as approximately every part of the wall would have been reached by flame from the center ignition at the same instant. Then we could consider the expanding sphere of flame to increase its radius at the rate of 59 in. per sec. and compress the gas and the air before it toward the walls. At first the gas and air mixture would be compressed adiabatically by the flame, just as occurs in my flame-starter already explained. After a certain progression the compressed gases at the walls in the act of igniting would move toward the center of the sphere, as well as to the walls, and so the flame at the central part would be recompressed adiabatically and the flame temperature would rise because of the work done upon it. The suction turbulence in the engine cylinder will no doubt modify this action but broadly the igniting point or points will always reach the highest temperature in the cylinder.

THE SPECIFIC HEAT OF FLAME

My later experiments on gaseous explosions on a new apparatus in the year 1900 and the experiments of many able and ingenious men in America and England following along similar lines proved among other things that the whole heat of combustion is not evolved at the maximum temperature and that either specific heat increases very considerably with the temperature or combustion is suppressed by some limiting cause such as dissociation, or combustion is continued after spread of the flame to a very great extent, or some other cause of heat loss exists than convection. To study the phenomena of heat

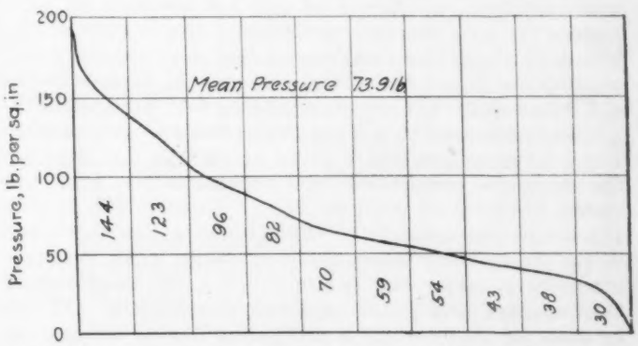


FIG. 20—DIAGRAM OBTAINED FROM THE CLERK FLAME-PRESSURE STARTER

loss and variation of specific heat I devised a new method of experiment in 1904 to which I have already referred. By it the actual working fluid behind the piston could be made to give information on these points during the progress of explosion, combustion and expansion in a working gas engine. The problem is a difficult one, and so far as my knowledge carries me, no previous attempt had been made even to determine a cooling curve for flame gases behind a moving piston.

The engine selected for the first experiments had a cylinder 14 in. in diameter with a 22-in. stroke; the exhaust and inlet-valve levers were supplied with longer pins than usual, so that the rollers mounted on these pins could be moved into or out of the range of the exhaust and inlet-valve cams. When each roller was caused to slide to one end of its pin, the cam passed clear of it and the lever was not operated. When at the other end of the pin the roller engaged with the cam and the lever operated in the usual way. A spring-and-trigger gear was arranged so that the rollers could be put out of range of the cams at any required instant. By this contrivance the engine could be run in its normal way in accordance with the Otto cycle at either light or heavy load, and any given explosion could be selected for the purpose of the experiment by operating the trigger at the proper moment. It was thus possible to run the engine at its normal speed under the usual propelling explosions, and to select at any given moment any particular charge, move the rollers out of the range of the cams immediately the charge entered, and so obtain an explosion and expansion stroke in the usual manner, with the usual charge. But both inlet and exhaust-valves were held closed and the charge retained in the cylinder. When the exhaust period was approached, the exhaust-valve remained shut, and accordingly the hot exhaust-gases were retained in the cylinder and compressed by the return stroke of the piston into the combustion space at the end of the cylinder. The energy of the flywheel was sufficient to keep up the rotations of the engine, with but little fall in speed during the short period of observation. The piston was thus caused to move to and fro, alternately compressing and expanding the hot gases which were contained in the cylinder so long as the gear prevented the operation of the inlet and exhaust-valves.

An indicator-card taken from such an initial explosion and expansion and the subsequent series of compressions and expansions is given at Fig. 21; *a b* is the ordinary compression-line indicating the compression of the charge before explosion, *b c* is the usual explosion-line, and *c d* the usual expansion-line after explosion. At *d*, however, instead of the pressure falling to atmospheric by the opening of the exhaust-valve, as the exhaust-valve remains closed no escape of the hot products of combustion is possible, and accordingly the return of the piston produces the compression-line *d e;* the next outward movement of the piston produces the expansion-line *e f,* followed by the compression-line *f g;* expansion-line *g h;* compression-line *h i;* expansion-line *i j;* compression-line *j k;* expansion-line *k l,* and so on. In this diagram the successive compression and expansion-lines have continued to be traced until the fall of pressure due to cooling brings the contents of the cylinder at the outer end of the stroke below atmospheric pressure, when the outer atmosphere opens the valves against the pressure of their springs, and so the experiment terminates. It will be observed that cooling is proceeding during the tracing of all these lines; had no cooling occurred on any particular expansion and compression stroke, the compression-line would lie on top of the expansion-line. Consider, for example, the moment represented by the point *e* when the piston is at the extreme inner end of its stroke; then the combustion space is filled with hot gases at a temperature and pressure corresponding to the point *e;* after a complete expansion and compression, a complete revolution of the crank, the piston is again at its innermost position, and the whole of the gases are again contained in the combustion-chamber at a pressure and temperature marked by the point *g*. This point *g* is lower than *e* and, as the weight of the gaseous contents has not changed, it follows that the temperature at *g* is lower than at *e*. The points *e, g, i, k* and *m* thus indicate the temperatures of the gases at the same volume at intervals of one revolution of the engine.

If the engine be running at 120 r.p.m., the temperatures represented by the points *g, i, k* and *m* give the successive temperature-falls suffered by the contents during successive revolutions, each lasting 0.5 sec. In the same way the successive temperatures of the gaseous contents at the outer ends of the stroke are given by the pressures at *d, f, h, j* and *l*. Call the successive temperatures at the outer end corresponding to these points t_1, t_3, t_5, t_7 and t_9 and the temperatures at the inner end of the stroke t_2, t_4, t_6, t_8 and t_{10}, corresponding to the points *e, g, i, k* and *m*. These temperature changes are partly due to heat-loss from the gases to the cylinder walls and partly due to work done on the piston by the gases or by the piston on the gases. The points at both ends of the stroke when properly dealt with give curves of temperature-fall due to heat-loss to walls.

Fig. 22 shows a compression and expansion diagram without the explosion-line. Consider first the series of points at the inner end of the stroke; obviously, if no cooling took place in the cylinder there would be no fall of temperature such as is shown between *e* and *g*. This drop is not entirely due to cooling, as will be seen when we consider what happens to the gases between the points *e* and *g*. When the engine piston expands the gases from *e* to *f* and compresses from *f* to *g*, a portion of the total heat has passed through the cylinder walls, but some work has also been done by the gases upon the piston. When the expansion *e f* takes place, the gases perform work on the piston equal to the area *e f o p;* when the compression *f g* takes place, the piston performs work on the gases equal to the area *f g p o*, so that more work has been performed by the gases on the piston than by the piston on the gases. Some work has therefore been done by the gases in the processes intervening between the points *e* and *g;* that is, part of the temperature-difference t_2-t_4 is due to work done; it is not all due to heat lost through the cylinder walls. The difference between the two work-areas is *e f g*, so that the temperature-fall t_2-t_4 is due partly to heat loss to walls and partly to work done by the gas.

If the specific heat of the gaseous mixture at the temperatures between t_2 and t_4 be known, then the temperature-fall due to the work-area *e f g* can be calculated, and when deducted from the total temperature-fall it gives the temperature-fall due to heat-flow through the cylinder walls. It is found that the specific-heat value need be only approximately known, as the temperature-fall equivalent of the work-area *e f g* is small in comparison with the total temperature-fall and little error is introduced by a considerable error in the specific-heat value. This method enables a true temperature-fall curve to be drawn, showing the progressive fall of temperature incurred from revolution to revolution under the actual

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SIDE GUIDE AND GRIPPER

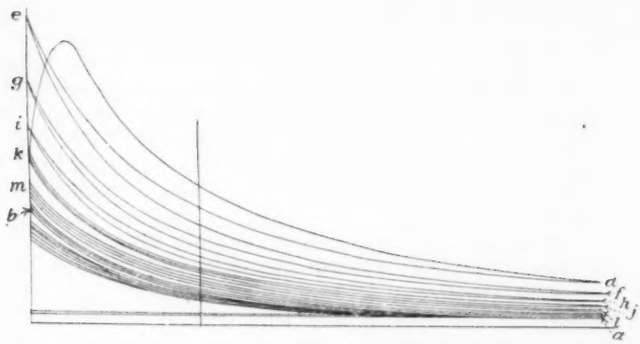

FIG. 21—DIAGRAM OF THE EXPLOSION AND ALTERNATE COMPRESSION AND EXPANSION OF HOT GASES IN AN INTERNAL-COMBUSTION ENGINE CYLINDER

working conditions of the engine. Proceeding in this way I have determined the cooling curve for the engine referred to; it is an Otto-cycle gas engine of 60 b.hp. built by the National Gas Engine Co., Ltd., of Ashton-under-Lyne. The experiments were made with Ashton coal-gas at the Company's works, Ashton.

Fig. 23 shows an indicator-diagram taken by my method from this gas engine, which had a bore of 14 in. and a 22-in. stroke, when working under a brake load of 50 hp. at 160 r.p.m. with the water-jacket at a temperature of about 71 deg. cent. (160 deg. fahr.). A Richards-Casartelli indicator was used. The temperature of the charge before compression was calculated at 95 deg cent. (203 deg. fahr.).

Proceeding in the manner described, I have prepared cooling curves from the engine under two conditions (*a*) with no load and the cylinder kept cool, and the engine running at 120 r.p.m., and (*b*) with full load and the jacket-water at 71 deg. cent. (160 deg. fahr.) and the engine running at 160 r.p.m. The cooling curves show the temperature-fall due to heat-loss, with mean tem-

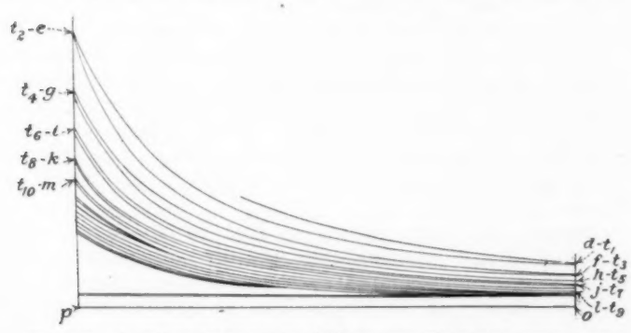

FIG. 22—A COMPRESSION AND EXPANSION DIAGRAM WITH THE EXPLOSION LINE OMITTED

peratures of the gases varying from 100 to 1500 deg. cent. (212 to 2732 deg. fahr.), and the exposure calculated to 1 sec. The curves show the rates of temperature-fall found under these conditions for complete strokes and partial strokes of three-tenths of the whole at the compression end. Fig. 24 gives the temperature-falls incurred per second for different mean-temperatures calculated in time.

Consider first the curves *a a'*. These correspond to the conditions in the engine cylinder when the engine is running at 120 r.p.m. without any load, so that very few ignitions keep it in motion, and while the water-jacket is kept cold by running water at 13 deg. cent. (55 deg. fahr.) freely through it. Under these conditions the end of the piston and the interior surface of the valves will be but little heated by the explosions, and the interior surfaces of the cylinder and combustion-space wall will tend to fall between the explosions to the water-jacket temperature of 13 deg. cent. (55 deg. fahr.).

The curve *a* is that for the complete stroke, while *a'* is for the partial first three-tenths of the stroke. Taking *a* first, it appears that the rate of temperature-fall per second for a mean temperature of 1300 deg. cent. (2372 deg. fahr.) is 1460 deg. cent. (2660 deg. fahr.); that is, that a complete stroke of the engine during which the mean temperature in the cylinder was 1300 deg. cent. (2372 deg. fahr.) would lose heat to the walls at a rate sufficient to produce a temperature-fall of 1460 deg. cent. (2660 deg. fahr.) per sec. The stroke in this case does not last a full second, but only ¼ sec., so that the real temperature-fall under these conditions would be

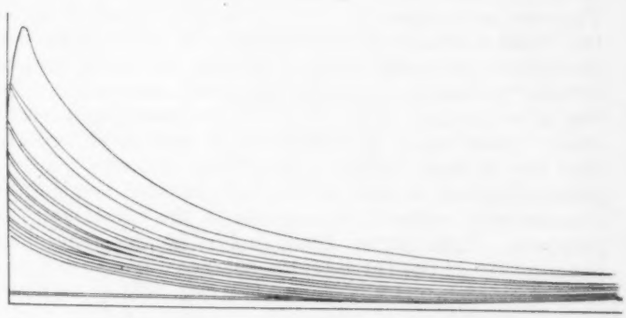

FIG. 23—INDICATOR DIAGRAM OBTAINED FROM A GAS ENGINE HAVING A CYLINDER 14 IN. IN DIAMETER AND A STROKE OF 22 IN.

1460 ÷ 4 = 365 deg. cent. (689 deg. fahr.). It is better, however, to express the temperature-fall in degrees per second.

The curve *a*, when prolonged to the zero of temperature-fall, cuts it at the temperature of 65 deg. cent. (149 deg. fahr.), which means that when the gases within the cylinder fall to the mean temperature of 65 deg. cent. (149 deg. fahr.), no further heat-loss occurs to the enclosing walls; that is, the mean temperature of the enclosing walls for the complete stroke of the engine must be 65 deg. cent. (149 deg. fahr.). The water outside does not succeed in keeping down the mean temperature

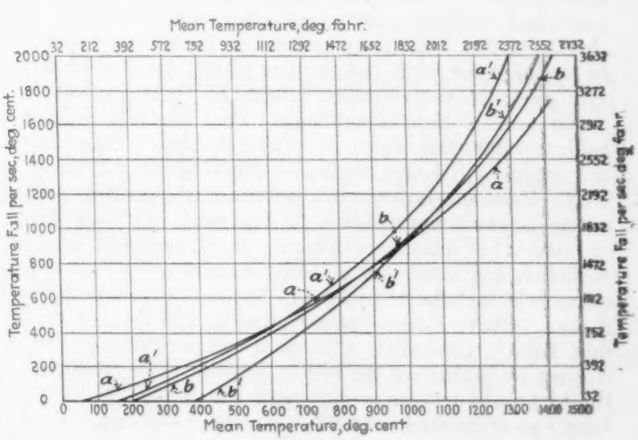

FIG. 24—FALL IN TEMPERATURE PER SECOND FOR DIFFERENT MEAN TEMPERATURES

of the interior surface, including valve surfaces and piston-end, to its own temperature of 13 deg. cent. (55 deg. fahr.). This curve thus gives an interesting indication of the mean temperature of the walls.

Taking curve a' in the same way, its general slope is greater than a, and it cuts the zero line at 165 deg. cent. (329 deg. fahr.), and crosses the curve a at a mean temperature of 610 deg. cent. (1130 deg. fahr.). Up to this point the temperature-fall is less than that of a for a given mean-temperature; above it the temperature-fall rapidly increases with increasing mean-temperature, so that the rate of fall is considerably greater in a' than in a at the mean temperature of 1300 deg. cent. (2372 deg. fahr.).

The fact that the intersection with the zero line is at 165 deg. cent. (329 deg. fahr.) indicates that the mean temperature of the cylinder walls is much higher for the inner three-tenths of the stroke than for the whole stroke. This was to be expected, because the proportion of piston-end, valve surface and other unjacketed surfaces becomes greater as the piston moves in; that is, the water-jacketed cylinder surface is covered as the piston moves in, so that the ratio changes, and therefore the mean temperature rises. Apart from this, however, it was to be expected that the surface temperature of the jacketed and unjacketed parts would be highest at the combustion-chamber end, where it is exposed to the maximum temperature. This curve, then, indicates that the mean temperature of the three-tenths surface during the three-tenths period is 165 deg. cent. (329 deg. fahr.), while the mean temperature of the whole cylinder surface during the whole stroke-period is only 65 deg. cent. (149 deg. fahr.) and this with the water in the water-jacket at 13 deg. cent. (55 deg. fahr.).

Comparing now the two curves, a a', at the mean temperatures 1300, 1200, 1100, 1000 and 900 deg. cent. (2372, 2192, 2012, 1832 and 1652 deg. fahr.), it is found that the rate of loss of temperature is less in curve a than in a' by the following percentages, calculated on the a values for the successive temperatures; nearly 26.0, 20.5, 16.0, 13.0 and 10.0 per cent. This clearly shows that, notwithstanding the diminutions of surface exposed in a given time at three-tenths stroke, as compared with whole stroke, the absolute temperature-fall rate is increased. This is probably due to the fact that the mean surface exposed diminishes more slowly than the mean density increases, so that the economical effect of increased density is not realized. Also, the existence of some turbulent motion may mask the other effects. This clearly shows that it is necessary to determine cooling in the cylinder with the moving piston, as the conditions are too little known to be predicted from explosions in closed vessels of fixed capacity. This becomes even more evident when the curves b b' are studied. These curves are taken while the engine is running at a load of 50 b.hp. Here the explosions are almost consecutive, and the water-jacket temperature is 80 deg. cent. (176 deg. fahr.), so that the interior surfaces, both jacketed and unjacketed, are much hotter than in curve a a'; as before, curve b is for whole stroke and b' for first three-tenths of stroke. Curve b cuts the zero line at 190 deg. cent. (374 deg. fahr.), indicating the mean temperature of the enclosing walls during the whole stroke. The condition of the internal surfaces is different, 190 deg. cent. (374 deg. fahr.) as compared with 65 deg. cent. (149 deg. fahr.), a very large increase in temperature. Curve b' cuts the zero line at 400 deg. cent. (752 deg. fahr.), also a much higher temperature. The continued explosion and the hot water-jacket have produced a very considerable change upon the surface temperature of the enclosing walls. Here also the curve b for the whole stroke is less steep than b' for the three-tenths stroke, but, owing to the high wall-mean-temperature at three-tenths, the curves do not intersect till the temperature of 1100 deg. cent. (2012 deg. fahr.) is reached. Below this figure the temperature-fall is less in b'; above that temperature it is greater.

Comparing b b' as a a' have already been treated at the same mean temperatures, it will be seen that for 1300 and 1200 deg. cent. (2372 and 2192 deg. fahr.) the temperature-fall is greater in b' than in b, but only 4 and 2 per cent respectively, calculated on b'; at 1100 deg. cent. (2012 deg. fahr.) the temperature-fall is practically equal; at 1000 deg. cent. (2012 deg. fahr.) b' is less by about 3 per cent on b', and at 900 deg. cent. (1652 deg. fahr.) is nearly 7 per cent less, also calculated on the value of b'. It is thus seen that for the practically interesting range of mean temperatures, 1300 to 900 deg. cent. (2372 to 1652 deg. fahr.) the temperature-fall given by the two curves varies but little, and this is due to the higher average temperature of the interior surface in the first three-tenths of the stroke. The point of intersection of the curves b b' is raised to such a high value that the actual heat-loss at about these temperatures remains nearly constant, although the two curves are undoubtedly different in slope. Now compare the curves a' b', and it will be seen that they are fairly parallel one to the other. Their general slope is very similar, so that, except at the lower end, they could almost be superimposed. It appears that the difference in absolute value of the temperature-fall for the given mean-temperatures was due mainly to the difference between the enclosing wall temperatures.

These experiments prove conclusively that cooling behind a moving piston depends largely on the varying temperature of the water-jacket, and still more on the varying mean-temperatures of the cylinder walls according to the condition of load and water-circulation. Although general laws may be deduced from closed-vessel experiments of fixed volume at varying initial pressures, yet the problem in the working engine is so complex that it is desirable to make many direct determinations on actual engines as to explosion and cooling in cylinders of varying dimensions before endeavoring to deduce any general formulas.

From the curves given in Fig. 24 and specific-heat values of the gaseous contents of the cylinder, heat-losses can be calculated on the explosion-expansion line independently of any knowledge as to the completeness of combustion at any point, and for this purpose I have determined the specific heat of the gases in the following manner: If a gas be compressed without gain or loss of heat from volume V_0 to V_1, and the temperature rises from T_0 to T_1, the mean specific heat of the gas per unit volume at 0 deg. cent. (32 deg. fahr.) and a pressure of 760 mm. (29.92 in.) of mercury at constant volume between the two temperatures is

$$C_v = W \div [\Psi_0(T_1 - T_0)]$$

where

C_v = the mean specific heat
W = the work done upon the gas
Ψ_0 = a constant depending upon the quantity of gas in the cylinder

This is also true of expansion as well as compression. The dynamical value of the rise or fall of 1 deg. cent.

(1.8 deg. fahr.) for 1 cu. ft. of the gas will be given by the formula:

$$D_v = W \div [V(T_1 - T_0)]$$

where

W = the work done on or by the gas in foot-pounds
V = the volume in cubic feet
D_v = the dynamical value in foot-pounds

It is evident that the method of operation just described affords a means of determining the heat-loss on expansion or compression-lines, and so permits the temperature fall or rise, due to the work done, to be determined at any temperatures. In this way I have experimented on the products of combustion contained within the gas-engine cylinder, and deduced the values of D_v for that working fluid at different temperatures. The experiments were numerous, and many difficulties were encountered; for the full discussion I refer to the paper[11] describing the experiments read by me before the Royal Society in 1906. It is sufficient here to give the values obtained for the working fluid, which was of the following composition:

	Percentage by Volume
Steam (assumed gaseous)	11.9
Carbon dioxide	5.2
Oxygen	7.0
Nitrogen	75.0
	100.0

TABLE 6—APPARENT INSTANTANEOUS SPECIFIC HEATS IN FOOT-POUNDS PER CUBIC FOOT OF WORKING FLUID AT 0 DEG. CENT. (32 DEG. FAHR.) AND 760 MM. (29.92 in.)

Temperature, deg. cent.	Temperature, deg. fahr.	Specific Heat at Constant Volume, ft-lb.
0	32	19.60
100	212	20.90
200	392	22.00
300	572	23.00
400	752	23.90
500	932	24.80
600	1,112	25.20
700	1,292	25.70
800	1,472	26.20
900	1,652	26.60
1,000	1,832	26.80
1,100	2,012	27.00
1,200	2,192	27.20
1,300	2,372	27.30
1,400	2,552	27.35
1,500	2,732	27.45

TABLE 8—HEAT BALANCE-SHEETS FOR "X" ENGINE PREPARED FROM CLERK DIAGRAMS

Card No.	22		23		24		Mean of the Three Cards
Heat-flow during Explosion and Expansion	Ft-lb.	Per cent	Ft-lb.	Per cent	Ft-lb.	Per cent	Per cent
Heat Contained in Gases at End of Expansion	12,480	15.4	14,000	17.0	13,100	16.0	16.1
Indicated Work	39,800	49.0	40,500	49.3	40,600	49.5	49.3
Total Heat	28,900	35.6	27,700	33.7	28,260	34.5	34.6
	81,180 (104 B.t.u.)	100.0	82,200 (106 B.t.u.)	100.0	81,960 (106 B.t.u.)	100.0	100.0

From cooling curves determined during the actual operation of the piston in the gas-engine cylinder in the manner described, and the dynamic value of the temperature-falls at high and low temperature in foot-pounds per standard cubic foot of working fluid, calculated from my specific-heat values as given in Tables 6 and 7, balance-sheets of the engine have been prepared from indicator measurements only. No gas measurements or determinations of heat-flow to jacket-water are required. Three diagrams were taken at full load of 50 b.hp., from which the balance-sheets in Table 8 were calculated.

All the values have been taken in foot-pounds. Taking Card No. 22, for example, the heat-loss due to cooling is equal to 12,480 ft-lb., the heat contained in the gases at the end of the expansion is equal to 39,800 ft-lb., and the positive loop of the indicator-diagram shows that the work done on the piston is 28,900 ft-lb. Now, if we add together these three items, we should get the total heat given to the charge for one stroke of the engine; this amounts, it would seem, to 81,180 ft-lb., which is equivalent to 104 B.t.u. Cards 23 and 24 vary slightly from this, but they each show 106 B.t.u.

If the combustion is nearly complete at the end of the stroke, the heat present found in this way should be equal to the heat evolved by the gas known to be present in the charge. The gas present in the charge is known to be approximately 0.183 cu. ft. at the working temperature of the measuring meter, and its lower calorific value was 574 B.t.u. per cu. ft. The heat of combustion of the gas is therefore $0.183 \times 574 = 105$ B.t.u. It is thus seen that the approximation is very close. The indicator has been able by the new method of application to account for the heat present in the charge.

The distribution of the heat varies to a small extent in the three diagrams, so that it is better to consider the mean result at the extreme right. In this balance-sheet each item is directly determined by a separate measurement, and no item is obtained by a difference as in the earlier balance-sheet. It is interesting, however, to compare a mean diagram taken by my optical indicator from the 9 x 17-in. gas engine at full load with hot-water

TABLE 7—MEAN APPARENT SPECIFIC HEATS IN FOOT-POUNDS PER CUBIC FOOT OF WORKING FLUID AT 0 DEG. CENT. (32 DEG. FAHR.) AND 760 MM. (29.92 IN.)

Temperature deg. cent.	Temperature deg. fahr.	Specific Heat at Constant Volume, ft-lb.
0- 100	32- 212	20.3
0- 200	32- 392	20.9
0- 300	32- 572	21.4
0- 400	32- 752	21.9
0- 500	32- 932	22.4
0- 600	32-1,112	22.8
0- 700	32-1,292	23.2
0- 800	32-1,472	23.6
0- 900	32-1,652	23.9
0-1,000	32-1,832	24.1
0-1,100	32-2,012	24.4
0-1,200	32-2,192	24.6
0-1,300	32-2,372	24.8
0-1,400	32-2,552	25.0
0-1,500	32-2,732	25.2

[11] See *Proceedings of the Royal Society*, vol. 85, p. 1.

jacket. A balance-sheet prepared by measuring the temperature-drop for the exhaust heat and the positive loop for the indicated power and deducting their sum from the total heat known to be present, is as follows:

	Per Cent
Heat-flow during Explosion and Expansion (by Difference)	21
Heat Contained in Gases at End of Expansion.	47
Indicated Work	32
	100

This balance-sheet, from a smaller engine, differs but slightly from the values calculated by my method which has been discussed. My mean balance-sheet, however, differs considerably from a balance-sheet calculated for the 14 x 22-in. engine at full or nearly full load by the Thermodynamic Standards Committee of the Institution of Civil Engineers, whose measurements consisted of brake horsepower, heat carried away by the water-jacket and radiated from the engine and heat discharged with the exhaust as determined by an exhaust calorimeter placed so as to cool the exhaust gases after passing out of the engine cylinder, all items being separately determined. The Committee's balance-sheet is compared with mine in Table 9.

TABLE 9—COMPARISON OF HEAT BALANCE-SHEETS

	Committee's Trials	Clerk Diagram Trials
Heat-flow during Explosion and Expansion	25.4	16.1
Heat Contained in Gases at End of Expansion	39.9	49.3
Heat in Indicated Work	34.7	34.6
	100.0	100.0

This discrepancy is mainly due to the fact that in ordinary trials the heat passing into the water-jacket system includes not only the heat-loss during explosion and expansion while the cylinder is entirely closed, but also heat from the exhaust gases, which passes into the jacket after the exhaust-valve opens during the exhausting stroke. This I have already explained.

From this discussion it is evident that heat-loss to the cylinder walls is much less than is popularly supposed in engines of modern design. It is often believed by inventors that one-half of the whole heat of the fuel passes away through the walls, and many schemes for working with red-hot walls have been, and, indeed, are sometimes yet, proposed under the idea that a great increase in thermal efficiency is possible by saving wall-loss. As a matter of fact, only a comparatively small increase in thermal efficiency is possible even if the whole of the wall-loss could be prevented.

I have made calculations from my own table of specific heats, which was fully discussed at the Institution of Civil Engineers some years ago, and they prove conclusively that in the National engine referred to, complete elimination of all heat-loss during explosion and expansion, using the compression-ratios and combustion temperatures actually attained in the working of the engine, would give an indicated thermal efficiency of 39.5 per cent instead of 34.7. That is, the actual engine gives 88 per cent of what an ideal engine of the same expansion, and using the same working-fluid, could give with heat-losses assumed to be absent. I have calculated the ideal efficiencies for different compression-ratios, assuming no heat-loss to walls, for maximum temperatures of 1600 and 1000 deg. cent. (2912 and 1832 deg. fahr.), with working fluid having variable specific heat according to my values, and for air standard having constant specific heat at all temperatures.

TABLE 10—IDEAL EFFICIENCIES WITH APPARENT SPECIFIC HEATS GIVEN BY CLERK'S EXPERIMENTS

$1/r$	Maximum Temperature 1600 deg. cent. (2912 deg. fahr.)	Maximum Temperature 1000 deg. cent. (1832 deg. fahr.)	Air Standard
1/2	0.195	0.200	0.246
1/3	0.286	0.293	0.360
1/4	0.354	0.356	0.430
1/5	0.384	0.394	0.480
1/7	0.439	0.443	0.550

From this table it will be seen that for a given compression-ratio the efficiency of air at constant specific heat is the highest, and that with varying specific heat, the lower the maximum temperature the higher the efficiency. For example, with a compression space of one-fifth the total volume, the air-standard efficiency is 0.48; working fluid of varying specific heat at 1000 deg. cent. (1832 deg. fahr.) maximum temperature, ideal efficiency 0.394, and at 1600 deg. cent. (2912 deg. fahr.) maximum temperature, ideal efficiency is 0.384. With both working fluids the ideal efficiency increases with increasing compression, and with the actual working fluid without any heat-loss, the efficiency increases as the temperature falls. The greater the specific heat, the lower is the thermal efficiency for a given expansion.

Another test was made with the same gas engine. In this case, however, the engine was driven electrically at 120 r.p.m., while the jacket was kept cold and the charge was taken from a large chamber which enabled its exact temperature to be measured. In this way it was possible to determine the suction temperature with accuracy. The important temperatures were (*a*) suction temperature 20 deg. cent. (68 deg. fahr.), (*b*) compression temperature 214 deg. cent. (417 deg. fahr.), (*c*) maximum explosion temperature at about 1/20 forward stroke 1380 deg. cent. (2516 deg. fahr.) and (*d*) temperature of exhaust in the cylinder before opening the exhaust-valve 650 deg. cent. (1202 deg. fahr.). The diagram was carefully taken by the same optical indicator. The balance-sheet as calculated is given in Table 11.

TABLE 11—HEAT BALANCE-SHEET OF A LARGE GAS ENGINE

	Per Cent
Heat-Flow during Explosion and Expansion.	37
Heat in Gases at End of Expansion	35.5
Indicated Work	27.5

The indicated work fell from 32.0 per cent to 27.5 and the heat-flow during explosion and expansion rose from 21.0 to 37.0 per cent as the result of work, the same mixture with a cold charge in a cold cylinder.

Conclusion

There are many questions which I have not dealt with, particularly the greatly increased mean-pressures obtained in the gasoline engine as compared with gas engines. The conditions of maximum thermal efficiency are the same for gas and gasoline. The fact that gaseous explosions are subject to a contraction of volume by the formation of carbonic acid gas and water, while hydrocarbons such as gasoline give a larger volume on combustion, would itself give increased mean-pressures, but

in addition the total heat-content of a gasoline-engine charge is over 100 B.t.u. per cu. ft. instead of 80 which is now the maximum with coal-gas; this also will cause further increase.

For full consideration of these points in England I look to my friend H. Ricardo who has written many valuable papers and made elaborate experimental investigations into the conditions of the maximum gasoline-engine thermal efficiency and output. He is at present completing a careful investigation into the characteristic features of different liquid fuels and is experimenting on the subject of knocking or detonating. Part of his work has been published and you are doubtless familiar with it. I am assisting by discussing the subject with Dr. Stanton and Mr. Fenning of the National Physical Laboratory. Interesting work on detonation is in progress there which will be published in due course.

Meantime it is difficult to say what causes a gaseous explosion to pass into detonation. I pointed out long ago that my early experiments with the explosion of compressed mixtures up to about 60 lb. above atmosphere, together with Sir Joseph Petavel's experiments up to 1100 lb. per sq. in., clearly show that increased compression in itself does not cause detonation. My experiments on suction turbulence with a hot engine and a hot mixture prove conclusively that higher temperature does not cause detonation. It seems that more recent experiments in closed vessels also point in the same direction. Auto-ignition by compression of piston or flame can raise the temperature of the whole body of the mixture to the igniting point and if ignition started equally from every point we should expect detonation or something very like it. Prof. Harold Dixon's experiments seem to show, however, that when auto-ignition starts it starts from one point and not from every point. Other experiments on this subject also are being made by Mr. Ricardo.

Purely chemical constitution undoubtedly causes knocking which may or may not amount to detonation in the sense of Berthelot's explosive wave. The difference may arise, as pointed out by Thomas Midgley, from the endothermic compared with the exothermic hydrocarbons.

I have already pointed out that knock can be got with any fuel by mechanical disturbance, and it may be possible that the reduction of total volume by increased compression may produce knock without increasing the rate of flame propagation simply by diminishing the distance of flame travel. For that the only remedy which I can suggest from present knowledge is the use of cold exhaust-gases either by exhaust-gas supercompression or by mixture with the incoming charge.

I look forward with much interest to the discovery of new facts by the younger engineers and scientific men of America and England. I am delighted to find that American engineers and chemists are doing so much good work in forwarding the solution of many difficult problems. Internal-combustion-engine problems fascinated me 44 years ago and my interest and wish to continue experimenting still last. It is a very great pleasure to feel that the brilliant American engineers, chemists and physicists of this great Society have taken up the good work which even in its early stage has wrought such important changes in the world.

RESEARCH WORK ON GEARS NEEDED

SUCCESS in designing gear drives to operate satisfactorily under specified conditions is very largely a matter of appreciation of what has been done before under very similar conditions. The Lewis formula, being a formula for strength only, is of no assistance in selecting the most suitable combination of pitch, diameter, face width and material for the purpose. Experience only can determine these proportions, because, even though the gears be made to a fine degree of accuracy, and be capable of transmitting the load without tooth breakage, it does not necessarily follow that they will give complete satisfaction when they are placed in operation.

Further investigation could be made to advantage to establish reliable data relative to the various factors that determine the smooth operation and life of gear trains. The research could be divided into three sections. The work in section one would be to establish the most suitable material for use under given conditions, the allowable stress, the allowable pressure, the resistance to abrasion, the elasticity and such things being found for different materials. Investigation in section two would deal with methods of manufacture, and an attempt would be made to define the degree of error permissible for various grades of workmanship. Research in section three would determine the influence upon the life and quiet operation of gears of such variables as peripheral velocity, load per unit of breadth, number of impacts, ratio of reduction, grade of workmanship, heating, and the disposition of metal in the gear rims and arms. Methods of gear mounting to absorb vibration, and the lubrication of gears would receive attention.

It will be agreed that successful research work along these lines would provide dependable data for the design of gears to meet any conditions in regard to load, speed, quiet running, life and such points. Alone, the Lewis formula can be used only to ascertain the maximum permissible load to insure freedom from tooth breakage; and, unfortunately, with many gears this is the only point checked by the gear designer, with the result that they are transmitting excessive pressure, so that backlash and noise develop in a short time. —R. J. Chapman in *American Machinist*.

AUTOMOBILES AID ALL OCCUPATIONS

EVERY business, every profession, gains through use of the automobile, according to the answers received by the National Automobile Chamber of Commerce to thousands of questionnaires sent to car owners throughout the country. Farmers show a gain of 68 per cent in their individual efficiency. This is an especially important figure, as the farmer is the largest class of car owners. Farmer-owned cars total over 2,500,000 or nearly one-third of all cars in use.

Bankers in rural districts find their cars productive in passing on mortgages and in getting acquainted with their out-of-town trade. The heavy gain here partially offsets the relatively small car utility in these occupations in the large cities where the business is more confined to the office. Manufacturers report a great saving in their time through car use as plants are frequently several miles from their homes, and motoring proves the most efficient means of transportation. Clergymen and school supervisors report a very large gain in the amount of work which they can accomplish.

Some Considerations in Tractor Service

By J. C. Thorpe[1]

Chicago Truck and Tractor Meeting Paper

IT requires no little amount of courage to appear before a group of engineers who are so familiar with the technical details of the farm tractor and attempt to present anything on the subject of service. Volumes have been written on the subject and there is scarcely a dealers' or engineers' association program on which it does not have a prominent part. The only reason for a repetition of discussion lies in the fact that we seem to be about as far from reaching our objective as we were several years ago. It is entirely probable that if we were to take a vote of this meeting, it would be very difficult to secure the opinions of any considerable number that might approve a definition of what we call "service." You will understand, therefore, that I do not have in mind the presentation of any new facts. It may be possible to dress up some of our present arguments in a little bit different attire so that their importance may be more strongly emphasized upon our mind. It is my purpose to present the subject in three phases: (*a*) general consideration, (*b*) the commercial aspect, and (*c*) the technical aspect.

General Considerations

One subject is very closely related to a question that has been very much discussed in the trade press and upon the floors of dealers' conventions during the past 3 or 4 years. This refers to, "Who is the logical tractor dealer?" Two groups have been involved in these discussions and have taken positions almost immeasurably apart. The old-time implement dealer says that he is the logical tractor dealer because he has been selling to the farm trade for years. He knows the farmer and his problems; also his habits of buying and selling. He is sure that irrespective of other considerations his own farm trade will buy tractors from him and from none else. He states, with emphasis, that no other merchant should encroach upon his territory and that the tractor factories should give him precedence over all others. The automobile dealer claims that he is the logical one to merchandise tractors because this equipment has very definite service requirements and he is thoroughly educated in taking care of the needs of those in his community who use automotive equipment. In my opinion all of this discussion has been misdirected and has failed entirely to reach the point. The dealers mentioned have failed to recognize the essential qualifications of a merchant in any mercantile community, namely, the ability to merchandise good goods at fair prices properly and having consummated sales to occupy the position of a consulting expert in relation to the customer.

It is not important that the old-time implement dealer is familiar with the farmer and his problems, nor that the automobile dealer has been trained in the art of giving service, when considering the substantial qualifications of a real merchant. Whoever of these groups measures his right to sell by the standard I have indicated to be the proper one is the logical tractor dealer. Because of the universal appeal of the farm tractor to the farming interests of the country, the sale of farm tractors offers opportunities for the development of "good-will" that are unequalled by any other merchandising activity. This very tangible asset is the essential cornerstone upon which the structure of every successful enterprise is built. It is always evident in thoroughly businesslike and fair dealings between the buyer and the seller and becomes intensified in the development of subsequent satisfactory business relations. The manufacturer, by producing an article of merit, honest advertising and a long period of fair treatment of the dealers, cooperating with them in promoting the interests of the customer, gradually attracts to himself and to his product a certain amount of public interest and approval. This degree of public approval is the measure of the manufacturers' good-will account. It is developed only by careful, honest and persistent effort through a period of years, but it may be destroyed by one false step.

We often hear, "What's in a name?" In my opinion that dealer who does not continually strive to make his name mean something in his community that will add to the economic wealth is missing what might be termed his logical objective and his right to permanency in his community may readily be questioned. Marshall Field has become a name to conjure with in the homes of this country, because of an attitude toward the customer based upon the conclusion that "the customer is always right." You are brought face to face upon the streets of St. Louis with the slogan "Don't say paper, say Star." My conclusion is that a tractor dealer should so persistently pursue the highest type of merchandising methods that his name will be inseparably identified in the mind of his market with the farm tractor. This result may be anticipated if the dealer outlines and carefully carries out a program that creates an impression of his thorough understanding of the subject and the adequacy of his service organization. Fundamentally, this conclusion is based upon the principle that tractor service meets an economic need; and to him who satisfies this need will come the reward of an enlarged and increasingly profitable business.

Cooperation between the dealer and the manufacturer is necessary in carrying out this program. The manufacturer is not a very tangible factor in the investment, judged from the standpoint of the purchaser, who seldom, if ever, comes in contact with the factory organization. And, while the manufacturer is dependent upon the good-will of the trade, as stated before, he must arouse public interest and approval through his intermediate trade factor, the dealer or distributor. This involves the maintenance of an adequate stock of repair parts, an efficient service and inspection department and an attitude of favorable forbearance with respect to service claims. It is the dealer to whom the customer looks for relief when equipment fails to measure up to his expectations, either in performance or in the quality of materials or workmanship. It is this mental attitude on the part of the buyer that often places the purchase upon the basis of a selection of the dealer rather than upon a selection of the specific item of equipment or merchandise. It is thus that the ability to "keep goods

[1]Barnett & Wilson Investment Co., St. Louis, Mo.

sold" becomes of equal importance with the art of selling, and presents a problem in which both manufacturer and dealer are vitally interested.

The Commercial Aspect

"Service" has become the pet slogan, expressed or implied, of nearly every business organization. It has been rolled like a choice morsel under the tongue of factory managers, accessory and supply jobbers, implement dealers, garage operators, crossroad repair shops and salesmen alike. It is to be regretted that claims to service superiority have not always been supported by a service plan tended to justify them. Despite the apparent familiarity with this magic word, it can be stated with assurance that it has almost challenged definition. I seriously question whether any considerable number of us here would spontaneously approve any definition that one of us might present. In the mind of the automobile owner it has meant anything from a "cursory once-over" accompanied by a copious discharge of so-called expert advice, to a semi-annual overhauling during the life of the car, without expense to the owner. Quite innocently, the term "service," whatever it may be understood or misunderstood to be, has become the vehicle of the most pronounced fallacy in the merchandising of machinery, damaging to manufacturer, dealer and customer; namely, the possibility of getting something for nothing. "Service" has been paraded in most alluring dress before the mind of the prospective purchaser by the unscrupulous salesman to the extent of creating an expectation of expenseless ownership. The rude awakening of the owner discredits the salesman, the dealer, the manufacturer and the product. There can be no such thing as free service. Such a conception is opposed to the economic law of compensation. To give service requires time and money, labor and materials, and for these someone must pay. In the end it is the consumer, because in the chain of trading events all the money must come from him.

The success of every merchandising enterprise is largely dependent upon the interpretation of this word service. Satisfying service for reasonable compensation always develops good-will between the seller and buyer. It goes far toward making the enterprise impregnable to the assault of depressing business conditions. If an article has merit, if it meets an economic need, somewhere there is someone with the inclination and the ability to buy, if he has the opportunity. Business depression may diminish volume and greatly increase selling costs and thus reduce profits but it does not completely destroy selling opportunities. A reputation for honest manufacturing, for courteous and courageous salesmanship and for rendering satisfying service can be expected to bring its reward in maintaining an open channel of trade when times are "hard," and a continually increasing volume of trade, the goal of every ambitious enterprise, in periods of normalcy. The bugbear free service often introduces factors of abuse and unfairness in competition. Sales are often made, apparently upon the basis of "who can give the most away." After the gross profit disappears in the negotiations, "free service" enters to bait the unsuspecting prospect further. It destroys confidence, separates business associates, debauches business character and attacks industrial progress. It makes impossible that close cooperation among dealers that is most healthful for trade development. It cheapens the product of the manufacturer and reflects discredit upon his selling organization. The term service, properly understood, thus loses its identity with the appearance of unfair trade tactics. If the purchaser, either through a misunderstanding of the service obligations of the dealer or by forethought, asks for and receives concessions incompatible with good business procedure, a fictitious value is placed upon the goods sold. Such a value cannot be maintained and thus another phase of price-cutting is introduced that is ruinous, not only to the individual dealer but to the industry. It would appear that the following definition may be a proper one:

> *Service*, as applied to the operation and maintenance of power-farming machinery, is the cooperation of the dealer with the owner, whether he be the original purchaser or not, during the life of the equipment in the dealer's district, to the end that the owner may secure continuous use of his investment at the lowest reasonable cost.

We all recognize that service is arousing the same general discussions in assemblies of representatives of the tractor interests that have been prevalent for years in the automobile industry. Unless the present agitation is curbed and thought directed by the leaders in the power-farming-equipment field along the lines of reason and good sense, it is probable that we shall experience the same difficulties and pass through the same period of chaos that has characterized the development of the motor-car.

Some confusion frequently arises in the interpretation of the factory warranty covering parts that fail due to faulty workmanship or material. Today, this warranty is limited to the replacement of such parts after they have been shipped to the factory, charges prepaid, inspected by the factory inspection department and found to come under such warranty. Repair parts are then shipped to the dealer or owner as the case may be, f.o.b. the factory shipping point. There are occasional departures from the factory policy of paying no labor charges. A clear and positive understanding of this warranty between the factory and the dealer, and through the latter, with the customer, is essential for the purpose of eliminating discussions with owners that often become embarrassing to all parties concerned and damaging to business.

Many factories maintain a corps of skilled mechanics who cover the territory to extend mechanical service to dealers with incompetent or no service men or to isolated owners who cannot appeal to the local dealers for service. The maintenance of this group of mechanics involves a material expense for which the manufacturer must be compensated. In most instances contracts do not differentiate between the dealers with adequate service facilities and those without. It is clear that this policy places a premium upon inadequate service and offers no encouragement to the improvement or development of service facilities.

It is a serious question whether we are near enough right in the present status of the factory warranty to begin the consideration of improved service with the conditions existing in the dealer body. My opinion is that a system of merchandising must be developed whereby a premium is placed upon adequate dealer service. This can be expected to place an ideal before the careless merchant that should prove an inspiration to attain to a higher plane of service activity. It should go far in attracting into the industry men of real commercial ability and achievement.

There are certain principles of design that appeal to the sales engineer, along the lines of which you are undoubtedly directing your energies. A tractor should possess such ease of control and operation as to make the employment of skilled labor on the farm unnecessary. I have frequently run across farmers who have persistently refused to consider the purchase of a tractor because they felt there was no one on the place to run it. The tractor should be of such pronounced simplicity and accessibility of mechanical detail as to guarantee a minimum loss of time and money for needed repairs, replacements or adjustments. It should have proved economy of operation and maintenance in order that it can make an appeal to the purchaser from the angle of an investment. The designer should have constantly in mind the fitness of the machine for the work it is proposed it shall do. It is to be regretted that this particular quality has been too much neglected in the tractor field with respect to design and to the selling policy of the factory and the dealer. I am convinced that much of the unfavorable criticism of the tractor has come from the fact that the purchaser was sold equipment that was unsuitable for his requirements.

I have been astonished at the lack of attention to what I consider a most important detail, the comfort of the operator. Salesmen talk loud and long about the merit of power-farming equipment as it relates to independence of weather and labor conditions. The farmer may await the arrival of settled weather before he begins his work and then by working 20 to 24 hr. a day catch up with his neighbor who is utilizing antiquated horsepower. The fact that he is to sit in a cramped position from sun-up to sun-down under the direct rays of a broiling sun upon a malleable iron seat upholstered in black enamel is never mentioned. No arnica or liniment is sold with the tractor and yet this is about as necessary an accessory to the machine as oil or water.

Frequent and expensive interruptions in service are occasioned by delay in securing repair parts. However careful the dealer may be to maintain his parts stock, occasions will arise when he must appeal to the factory for assistance. Frequently this assistance is not given promptly because no parts are available from the factory stock. This presents a production problem that must have attention if power farming is to receive the approval it warrants. It would seem that the great desire for the production of completed units has obscured the question of what shall be done for them after they are sold and put to work. A proper scheduling and control of parts production should eliminate this difficulty. Too little attention is given the dealer in the selection of his parts stock. The industry is too young and the experience of the dealers too limited to expect the exercise of accurate judgment respecting parts requirements. It is highly desirable that this problem be given careful consideration by the engineering departments, in the preparation of parts lists based upon actual field experience, which can be placed in the hands of the dealers when executing their contracts.

Some of the most conspicuous successes in the industrial development of our country have been based upon the development of a training school within the enterprise. I have in mind the many special apprenticeship courses that are available for those requiring special training within either the parent organization or its external connections. Service will not be organized upon the most desirable plane until men are available who will take their places as skilled mechanics in the great dealer organization. Some hit-and-miss plans of training tractor mechanics are in operation in several factories at this time. The manufacturer of power-farming equipment who gets a real vision of this problem and outlines a definite program of specialized training for tractor mechanics or service men, will secure a wonderful asset. The organization of service schools by the tractor companies shows an appreciation of the problems in operation and maintenance that confront the tractor operator. The principle is right, the motive commendable, but the method wrong in most instances, in my opinion. Too little attention is given to differentiating between field operations and service station or shop operations. It is not wise, except in rare instances, to encourage the farmer to undertake service-station operations with the inadequate shop facilities existing on the average farm. And yet it seems that most of the instructors in charge of the mechanical-service schools place the greatest emphasis on taking magnetos apart, charging the magnets and reassembling the unit, taking down the crankcase and refitting bearings, etc., giving entirely too little attention to emergency field operations and ordinary inspection.

Most of the problems presented would respond to a closer cooperation between the sales and the engineering departments. This should develop a greater sympathy between the departments relating to the difficulties that are of mutual interest. Greater interest of the engineer in field activities would go far toward a solution of mechanical service as it relates to the design, and a keener interest in the problems of the engineer on the part of the sales department would unquestionably enhance the effectiveness of the selling campaign.

I can think of no development that would be of more permanent and immediate benefit to this great industry than the organization in every factory of a merchandising and engineering research department that would link up and conserve the energies of selling and production. In its relation to service, this department would be of incalculable value to the dealer, and if to the dealer, to the American farmer who yet needs to be "sold and kept sold" on the power-farming idea.

HIGHWAYS

IT has been found that a tax for a well-prepared highway is less of a burden than the age-long discouraging mud tax which has been one of the greatest drawbacks in rural development everywhere.

Successful rural education, as exemplified in the modern consolidated schools, cannot be conducted with a real measure of success unless from each school there radiate from 30 to 50 miles of good roads, over which autobuses rapidly course their way with their loads of children and youth, back and forward from school and home.—P. P. Claxton.

MARCH 1921 ISSUE OF DATA SHEETS

THE March 1921 data sheets containing the revisions and additions which were adopted by the Standards Committee in January were mailed to the members early in May. Members who have not done so should sign and mail the return postal card enclosed with each set.

Elements of Automobile Fuel Economy

By W. S. JAMES[1]

SEMI-ANNUAL MEETING PAPER *Illustrated with* CHARTS AND DIAGRAMS

THE viewpoint from which this paper has been written has been purely analytical. An attempt has been made, first, to analyze and state the factors affecting the power requirements of cars as rubber-tired vehicles of transportation over roads; second, to analyze and state the factors affecting the amount of power supplied the car as fuel to produce at the road the power required for transportation. Wherever possible, quantitative values have been given to indicate our present knowledge of the relations between the factors involved.

The power required to propel rubber-tired vehicles over roads is delivered to the road by the wheels as thrust or tractive force which is used (*a*) to overcome wind-resistance, (*b*) to overcome the resistance to the rolling of rubber-tired vehicles, (*c*) to produce linear acceleration of the car masses and angular acceleraton of the wheels and (*d*) to overcome gravity deceleration when climbing hills.

The thrust or tractive force required to overcome wind-resistance is proportional to the projected frontal area of the car and to the square of the velocity of the car relative to the air. Stated symbolically

$$F = CAV^2$$

where

A = Area in square feet
C = Constant of proportionality
F = Force in pounds
V = Velocity in miles per hour

The constant of proportionality C varies with the type of body and no reliable information seems to be available on the effect of changes in body shape on this figure. Values of C from various sources are given in Table 1. The measurement of the projected frontal area of 17 different representative makes of car gave an average value of 26 sq. ft., the minimum being 24 and the maximum 30 sq. ft.

The thrust or tractive force required to overcome the road-resistance to rolling of rubber-tired vehicles is nearly independent of speed (See Table 2) and depends on (*a*) the weight of the vehicle, (*b*) the character of the road surface, (*c*) the construction of the tires, (*d*) the inflation-pressure of pneumatic tires and (*e*) on the type of wheel-bearings. As the last three items vary directly with the weight of the car, numerical values for the tractive force necessary to overcome the rolling resistance are usually given in terms of pounds of force per 1000 lb. of car weight or per ton of car weight. The former unit will be used in this paper. The rolling resistance of rubber-tired vehicles over different types and conditions of road surface varies widely. Values of this resistance from various sources are collected in Table 3. There is little information available as to the effect of tire construction on rolling resistance. The values in Table 4 indicate the magnitude of the variation in resistance to be expected. Little has been published on the resistance of different types of wheel-bearings and on the effect of the type of lubricant used and its temperature. Values obtained by Lockwood and Riedler are given in Tables 2 and 5. Table 2 indicates that bearing resistance probably increases in proportion to the speed. It is however, a small percentage of the total rolling loss. In Table 5 it is assumed that in the case of a six-cylinder Chalmers chassis the bearing losses in the front and rear wheels are equal. The load on the front wheels was 1145 lb. and 1545 lb. on the rear wheels. The tires were 32 x 4 in. and the inflation-pressure was 74 lb. per sq. in.

TABLE 1—VALUES OF CONSTANT C FOR WIND-RESISTANCE

Source	Value of C
Hunsaker, Marks' Handbook[2]	0.00328
Riedler, The Scientific Determinations of the Merits of Automobiles	
Electric Vehicle with Closed Body[3]	0.00318
30 hp. Renault Car with Open Body[3]	0.00324
40 hp. Daimler with Open Body[3]	0.00324
Browne and Lockwood[4]	0.00300
Favary, Motor Vehicle Engineering[5]	0.00400
Heldt, Marks' Handbook[6]	0.00420
Hütte[7]	0.00275

[2] This value is based on a flat plate from 5 to 10 ft. square normal to the wind. It is hardly possible that the coefficient of an automobile would exceed that of a flat plate as there are few shapes used with larger coefficients.

[3] These values were used to compute car performance from test-stand results. All other resistances were measured. Road-performance tests of cars checked laboratory results remarkably well.

[4] See TRANSACTIONS, vol. 10, part 1, p. 68. Road tests on one car to check test-stand results showed power actually required on road to be 2 per cent higher at 20 m.p.h. and 5 per cent higher at 30 m.p.h. than values computed using this figure. At 30 m.p.h., where the wind-resistance is a large proportion of the total resistance, an increase in the wind-resistance coefficient of 6 or 7 per cent would bring the road tests in agreement with the stand tests and the coefficient close to Riedler's figures.

[5] Data for flat plates from United States Signal Service at Mt. Washington, N. H. This value is probably high.

[6] Probably high; see last sentence in footnote 2.

[7] Taken from wind-resistance of fast trains. Probably low for automobiles because of the length of even a short train.

The data presented show that for a given car-weight the variation in road-surface resistance is by far the most important item to consider in the reduction of rolling resistances.

The tractive force required to give a linear acceleration to the mass of the car and an angular acceleration to the wheels is directly proportional to the weight of the car and the weight and moment of inertia of the wheels. The force required to accelerate the wheels is about 2 to

[1] M.S.A.E.—Associate physicist, Bureau of Standards, Washington.

4 per cent of the total tractive force and can be neglected. An acceleration of from 3 to 4 ft. per sec. per sec. is usually demanded in good performance, but accelerations as high as 5 and 6 ft. per sec. per sec. are very uncomfortable for passengers. The tractive force required per 1000 lb. of car-weight for several rates of acceleration, including an additional force of 3 per cent for wheel accelerations, is given in Table 6.

The tractive effort required to overcome grades is equal to the product of the car-weight, gravity acceleration and the sine of the angle of grade. For grades less than 14 per cent the per cent grade can be used in place of the sine of the angle with an inaccuracy of only 1 per cent. For grades less than 6 per cent the error is inappreciable. There seems to be no general rule followed in country road construction for maximum permissible grades. In cities the grades are kept below 10 per cent unless extraordinary conditions must be met. Tractive force per 1000 lb. of car-weight for grades up to 14 per cent is given in Table 7.

To illustrate the relation existing between the three[8] major power demands, wind-resistance, road rolling-resistance and acceleration, the characteristics of the average 1921 American car as given by *Motor*[9] have been computed and the results are given in Table 8. It will be noticed that the tractive force available to overcome

[8] The power or tractive effort required for acceleration and hill-climbing are performance requirements independent of the road surface and wind-resistance. They can be considered as one power-demand interchangeable in application as both are essential accelerations and seldom demanded at the same time. The only point of difference lies in the fact that hill-climbing does not necessarily involve wheel acceleration. This item is small and for the purposes of this illustration can be neglected.

[9] See *Motor*, January, 1921, p. 67.

TABLE 2—RESISTANCE TO ROLLING OF PNEUMATIC-TIRED VEHICLES AT SEVERAL SPEEDS

Car	Speed, m.p.h.	Front Wheel Resistance per 1000 Lb. of Car Weight, lb. Total	Tires	Bearing and Windage	Rear Wheel Resistance per 1000 Lb. of Car Weight, lb. Total	Tires	Bearing and Windage	Total Wheel Resistance per 1000 Lb. of Car Weight, lb.
30-hp. Renault[10]	6.2	5.4	4.5	0.9[12]	...	...	...	23.3
	12.4	5.4	4.5	0.9	17.9	...	...	22.4
	18.7	5.7	4.5	1.2	16.7	...	...	20.4
	24.9	6.1	4.5	1.6	14.3	...	...	19.2
	31.1	6.3	4.5	1.8	12.9	...	...	21.3
	37.3	6.8	4.6	2.2	14.5	...	...	21.3
	43.6	7.4	4.6	2.8	17.1	...	...	24.5
40-hp. Daimler[10]	6.2	6.4	5.6	0.8[12]	...	...	...	...
	12.4	6.4	5.6	0.8	...	...	...	...
	18.7	7.0	5.9	1.1	16.6	...	...	23.6
	24.9	7.3	5.7	1.6	17.3	...	...	24.6
	31.1	7.7	5.8	1.9	17.4	...	...	25.1
	37.3	7.8	5.4	2.4	18.0	...	...	25.8
	43.6	8.6	5.8	2.8	18.9	...	...	27.5
	49.7	9.0	5.8	3.2	18.3	...	...	27.3
Mercedes Electric[10]	6.2	7.4[13]	...	...	14.5[11]	...	...	21.9
	12.4	7.9	...	...	14.7	...	...	22.6
	18.7	8.4	...	...	15.8	...	...	24.2
	24.9	8.9	...	...	17.9	...	...	26.8
	31.1	9.2	...	...	21.5	..	...	30.7
45-hp. Bussing Motor Truck[10]	6.2	3.8	...	...	13.7	8.2[13]	5.5	17.5
	9.3	4.8	...	...	13.3	8.4	4.9	18.1
	12.4	5.3	...	...	13.7	8.5	5.2	19.0
	15.5	5.9	...	...	14.4	10.8	3.6	20.8
100-hp. Benz Racing Car	31.1	7.1	...	...	24.0	...	...	31.1
	43.6	7.6	...	...	30.0	...	...	37.6
	55.9	5.9	...	...	31.0	...	...	36.0
	68.4	10.4	...	...	31.0	...	...	41.4
	80.7	13.6	...	...	31.0	...	...	44.6
	93.3	14.0	...	...	29.0	...	...	43.0
75-hp. Adler Racing Car[10]	24.9	10.7	...	...	34.7	...	...	45.4
	37.3	10.7	...	...	35.6	...	...	46.3
	49.7	10.7	...	...	38.7	...	...	49.4
	62.1	12.8	...	...	36.3	...	...	49.1
	74.7	10.7	...	...	36.5	...	...	47.2

Car	Tires	Inflation-Pressure, lb. per sq. in.	Speed, m.p.h	Rolling Resistance of Front Wheels per 1000 Lb. of Car Weight, lb.
A[11]	32x4 Silvertown Cord	60	20	10.4
			30	10.4
			40	12.3
B[11]	32x4 Plain Fabric	55	21	21.1
			27	21.8
			34	20.5
			41	21.3
C[11]	35x5	60	21	15.7
			27	16.0
			34	16.3
			41	16.1

[10] See Scientific Determination of the Merits of Automobiles by A. Riedler.
[11] Power Losses in Pneumatic Tires by E. H. Lockwood, published in the TRANSACTIONS, vol. 12, part 1, p. 377.
[12] Annular ball bearings on the Renault and Daimler cars.
[13] Dual solid tires on rear wheels and single solid tires on front wheels.

TABLE 3—RESISTANCE TO ROLLING OF PNEUMATIC-TIRED VEHICLES OVER VARIOUS ROAD SURFACES

Road Surface	Condition	Rolling Resistance per 1000 Lb. of Load, lb.	Authority
Concrete		9 to 19	*A*
Asphalt	Good	7	*B*
	Hard Smooth	11	*C*
	Poor	13	*B*
	Pavement	21 to 31	*D*
Wood	Paving	13	*B* and *C*
Macadam	Smooth and Dry	15	*D*
	Good	17	*C*
	Best	19 to 21	*B*
	Slightly Defective Reasonably Dry	18	*D*
	Good, Softened by Rain	20	*D*
	Dry and Dusty	21 to 24	*E*
	Slightly Defective, Softened by Rain	22	*D*
	Ordinary	22 to 27	*B*
	Hard Best, Wet	24 to 32	*E*
	Bad State of Repair	25	*D*
	Good, Softened	35	*E*
	Soft	43	*B*
	Bad	22 to 45	*C*
Dirt	Dry and Good	15	*D*
Belgian Block	Irregular	22	*D*
Granite Block	Good	27	*F*
Flint	Rolled	37	*F*
	Soft	46	*F*
Cobbles	Ordinary	58	*B*
	Bad	up to 110	*C*
	Very Bad	110	*B*
Clay	Hard Dry	45	*B*
	Best	49	*B*
Gravel	Best	25	*B*
	Loose	75 to 100	*D*
Sand	Road	160	*B*
	Loose	250	*B*
Railroads		4½	*B*
Tramways		13	*B*
"Good" Roads		18 to 22	*G*
Asphalt		10	*B*
		18	*F*
Macadam		27	*F*
"Heavy" Roads		27 to 39	*G*
Cobbles		27	*B*
		26	*C*
Sand		150 to 200	*D*
		160 to 250	*C*

List of Authorities

A Practical Testing of Motor Vehicles by A. B. Browne and E. H. Lockwood, published in the TRANSACTIONS, vol. 10, part 1, p. 68.

B Diagrams for Automobile Power Calculations by George Watson, published in *American Machinist*, Dec. 20, 1906, p. 806.

C Motor Vehicle Engineering by E. Favary.

D M. Forestier in Proceedings of Second International Automobile Congress held at Paris in 1902.

E H. Rodier in *Automobile*, vol. 13.

F The Auto Engineers Year Book, for 1920.

G Accelerometer Tests by H. E. Wimperis, published in *Proceedings of the Institution of Automobile Engineers*, vol. 8, p. 281.

wind and road-resistance and produce acceleration varies less than 4 per cent over the driving range of speeds from 10 to 35 m.p.h.; that the tractive force available to overcome rolling resistance and produce acceleration varies more than 25 per cent over the same range of speeds; and further that grades of from 9 to 4.5 per cent can be negotiated at speeds from 20 to 35 m.p.h., dependent on the road-resistance to rolling. Should the car characteristics chosen be representative of the present American product meeting the demands of the driving

TABLE 4—RESISTANCE TO ROLLING OF PNEUMATIC TIRES OF DIFFERENT TYPES OF CONSTRUCTION AND SIZES[14]

Tires	Inflation Pressure, lb. per sq. in.	Total Load, lb.	Resistance per 1000 Lb. of Axle Load, lb.[15]
32 x 4 Front Wheels Silvertown Cord	60	1,120	9
35 x 5 Front Wheels Silvertown Cord	60	2,100	13
32 x 4 Front Wheels Fabric Tires	55	1,140	19
32 x 4 Front Wheels Cord Tires	55	1,140	12

[14] See Power Losses in Pneumatic Tires by E. H. Lockwood, published in the TRANSACTIONS, vol. 10, part 1, p. 377.

[15] Values are reduced 21 per cent to eliminate bearing losses.

public, the performance demands of the public are in no way unreasonable with our roads as they are today.

Fuel conservation from the point of view of power demands of the car would be greatly furthered by a sound, far-sighted good-roads program. The power demands to overcome grade and high average rolling resistance would

TABLE 5—ANALYSIS OF RESISTANCE TO ROLLING OF A SIX-CYLINDER CHASSIS[16]

	Resistance per 1000 Lb. of Car Weight, Lb.
Front tires only	6.8
Rear tires only	6.6
Front bearings only	1.7
Rear Bearings and Transmission	6.7
Total	21.8

[16] See Power Losses in Pneumatic Tires by E. H. Lockwood, published in the TRANSACTIONS, vol. 10, part 1, p. 377.

not only be reduced but, more important still, car-weights could be reduced without any sacrifice of constructional sturdiness. Any reduction in car-weight means an al-

TABLE 6—TRACTIVE FORCE REQUIRED FOR ACCELERATION

Acceleration, ft. per sec. per sec.	Tractive Force per 1000 Lb. of Car-Weight, lb.[17]
0.5	16
1.0	32
1.5	48
2.0	64
2.5	80
3.0	96
3.5	112
4.0	124

[17] An additional 3 per cent is assumed for wheel acceleration.

most proportionate decrease in the power required and therefore in the fuel to supply the power.

The processes involved in the production of power at

TABLE 7—TRACTIVE FORCE REQUIRED TO OVERCOME GRADES

Grade, per cent	Tractive Force, per 1000 Lb. of Car-Weight, lb.
1	10.0
2	20.0
3	30.0
4	40.0
5	50.0
6	59.9
7	69.8
8	79.7
9	89.7
10	99.6
11	109.4
12	119.3
13	128.5
14	138.6
15	148.0

TABLE 8—ROAD CHARACTERISTICS OF THE AVERAGE 1921 AMERICAN CAR

Car Speed, m.p.h.	Available Engine Effort[18] per 1000 Lb. of Car-Weight, lb.	Air-Resistance[19] per 1000 Lb. of Car-Weight, lb.	Thrust Available[20] for Road-Resistance and Acceleration per 1000 Lb. of Car-Weight lb.	Thrust Available for Acceleration with Road-Resistances per 1000 Lb. of Car-Weight of		
				10 Lb.	20 Lb.	30 Lb.
15	107.3	4.9	102.4	92	83	70
16	105.2	1.8	103.4	93	83	73
20	107.6	8.8	98.8	89	79	69
25	106.0	13.4	92.6	83	73	63
30	103.9	19.2	84.7	75	65	55
35	101.2	26.0	75.2	65	55	45
40	98.0	34.1	64.9	55	45	35
45	94.1	43.4	50.7	41	31	21
50	86.8	53.8	33.0	22	12	2

[18] The data used in this computation were a maximum of 33 hp. at 2270 r.p.m.; a transmission and rear-axle efficiency of 85 per cent; the torque-speed curve was proportional to that given by Fig. 24 in a paper by A. L. Nelson entitled Fuel Problem in Relation to Engineering Viewpoint, published in THE JOURNAL for February, 1921; 32-in. tires; a rear-axle ratio of 4.42 to 1; a car-weight of 3096 lb. without any load and a passenger weight of 750 lb.

[19] Projected frontal area of car 26 sq. ft. The division of the total car resistance by the car-weight does not mean that the air-resistance varies with the car-weight. It was done for ease of comparison with the available thrust and road-resistance for 1000 lb. of car-weight.

[20] Ten pounds tractive force per 1000 lb. of car-weight is nearly equivalent to the tractive force required to move 1000 lb. up a 1-per cent grade.

the rear-wheel rims from fuel supplied the engine may be divided into four main groups; (*a*) the preparation of an explosive mixture of fuel and air, (*b*) the transformation of the chemical energy latent in the explosive mixture into gas pressure, (*c*) the transformation of the gas pressure produced into crankshaft torque and (*d*) the transformation of crankshaft torque to thrust at the road surface. The division lines between the first three items are not definite and can be drawn in several ways. In this paper the transformation of chemical energy into gas pressure is considered as starting with the passage of the spark through the explosive charge and terminating with the ceasing of combustion.

The preparation of an explosive mixture of air and fuel involves three major factors; (*a*) proportioning the proper weight of air to a given quantity of fuel, (*b*) mixing the fuel and air as intimately as possible, and (*c*) controlling the weight of combustible mixture used in a unit of time.

In proportioning the air and fuel it is important to know the limiting values of the ratios of weight of air to weight of fuel which will explode under cylinder conditions. There are some data available on this subject but they are inadequate. The results of some of the experiments made in 1915 by the Bureau of Mines[21] on the explosive range of mixtures of air and gasoline vapor are given in Table 9. The gasoline had an end-point of 140 deg. cent. (284 deg. fahr.) and its specific gravity at 15 deg. cent. (59 deg. fahr.) was 0.689 or 73.2 deg. Baumé. The mixture ratio[22] or the number of pounds of air per pound of gasoline was 27 to 34 for the lean explosive limit[23] and 6 to 7 for the rich explosive limit. Burgess and Wheeler[24] have measured the lower limit of inflammation of methane, ethane, propane, butane and pentane at atmospheric pressure and temperature. Their results show that the leanest explosive-mixture ratio varies from 29 for methane to 27 for pentane. Burrell and Robertson have found that up to 5 atmospheres an increase in initial pressure of an explosive mixture of methane and air has no effect on the lean explosive-mixture limit. They also report that it has been found in France that in the case of hydrogen-air mixtures an initial pressure of 40 atmospheres has no effect in changing the lower limit of inflammability. The same authors have shown that an increase in initial temperature from 23 to 500 deg. cent. (73 to 932 deg. fahr.) increases the possible leanness of the explosive mixture about 30 per cent. It is probable that heavier members of the parafin series follow the same general laws as methane. Indefiniteness is introduced into all measurements made on explosive range by the changing rate of inflammation with various mixture ratios.

The results of these measurements on explosive-mixture range are not directly applicable to internal-combustion-engine conditions for two reasons. First, the effect of heat losses, method of ignition and turbulence have a marked effect on the results in small glass bombs and these factors are very different in sealed glass bombs and in engine cylinders. Second, in an engine cylinder the explosive charge is diluted by the products of combustion from the previous working stroke. At the end of the exhaust stroke there remains in the clearance volume an almost constant weight of exhaust gas irrespective of the engine speed and load. As the weight of unburned charge taken in decreases with any decrease in the load, the percentage of exhaust-gas dilution increases. The effect of inert-gas dilution on explosive range of gasoline-air mixtures has not been extensively investigated. Fig. 1 is drawn from admittedly meager data on this subject. It indicates that the less the stratification or the greater the turbulence of the cylinder contents, the richer the leanest mixture which will fire regularly must be. From the viewpoint of fuel economy, the lean explosive limit of the mixture of air, fuel and exhaust gases in the cylinder at ignition sets a maximum limit of leanness

TABLE 9—EXPLOSIVE RANGE OF MIXTURES OF GASOLINE VAPOR AND AIR

Initial Temperature, deg. cent.	deg. fahr.	Lean Explosive Limit
23	73	23 to 25
200	392	25 to 27
300	572	30 to 31
400	752	31 to 37

[21] See Bureau of Mines Technical Paper No. 115 entitled Inflammability of Mixtures of Gasoline Vapor and Air by G. A. Burrell and H. T. Boyd.

[22] The original data are given in percentages of gasoline vapor. The mixture ratios were computed from the experimental results on the assumption that the mixture giving a maximum of carbon dioxide on carburetion was an average chemical combining ratio of the paraffin series of 5.0.

[23] The lean explosive limit of a mixture of air and gasoline vapor from 50 to 60 deg. Baumé gasoline was found to be about 25.

[24] See Lower Limit of Inflammation of the Parafin Hydrocarbons in Air, published in the *Journal of the Chemical Society* (England), vol. 99, p. 2015.

and, therefore, thermal efficiency unless charge "stratification" is resorted to.

Within the explosive proportion limits there are two mixture proportions which are interesting from the point of view of internal-combustion engines and one from an academic viewpoint. These are (*a*) maximum economy mixtures, (*b*) maximum power mixtures and (*c*) chemically "correct" mixtures. Excellent experimental work has been done by several observers on maximum-economy mixtures and it is concluded that the mixture for maximum economy is the leanest mixture on which the engine will fire regularly,[25] usually about 16 to 1. Mixture ratios for maximum-power development have also been carefully studied,[26] and found to be practically independent of speed and load and to vary from 11 to 1 to 13 to 1.

The chemical combining ratios of about 40 compounds of four of the principal series of hydrocarbons found in automotive-engine fuels are given in Table 10. The

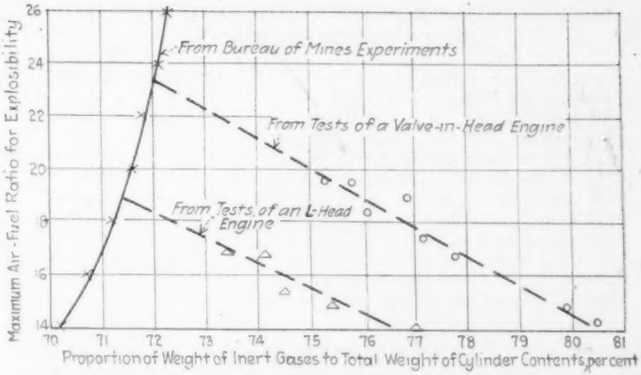

FIG. 1—EFFECT OF AN INCREASE IN THE WEIGHT OF THE INERT GASES ON THE MAXIMUM AIR-FUEL RATIO FOR EXPLOSIBILITY

[25] See Appendix 1 to this paper.

[26] See Mixture Requirements of Automobile Engines by O. C. Berry, published in THE JOURNAL, November, 1919, p. 364, and Carburetion Requirements of a Typical Gas Engine by P. S. Tice, published in *Automotive Industries*, June 24, 1920, p. 1452.

TABLE 10—PROPERTIES OF HYDROCARBON COMPOUNDS FOUND IN ENGINE FUELS

Compound	Boiling Point at Atmospheric Pressure, deg. cent.	deg. fahr.	Chemical Combining Ratio of Air and Fuel	Vapor Volume, cu. ft. per lb.	Heating Value B.t.u. per lb.[27]	B.t.u. per cu. in.[28]
			Parafin Series			
C_5H_{12}	36.3	97.3	15.24	4.98	.....	.....
C_6H_{14}	69.0	156.2	15.15	4.17	19,360	0.0545
C_7H_{16}	98.4	209.1	15.09	3.58	19,260	0.0545
C_8H_{18}	125.5	257.9	15.03	3.14	19,180	0.0547
C_9H_{20}	150.0	302.0	15.00	2.80	.....	.....
$C_{10}H_{22}$	173.0	343.4	14.97	2.52	.....	.....
$C_{11}H_{24}$	195.0	383.0	14.95	2.30	.....	.....
$C_{12}H_{26}$	214.0	417.2	14.93	2.11	.....	.....
$C_{13}H_{28}$	234.0	453.2	14.91	1.95	.....	.....
$C_{14}H_{30}$	252.0	485.6	14.89	1.81	.....	.....
$C_{15}H_{32}$	270.0	518.0	14.88	1.69	.....	.....
			Aromatic Series			
C_6H_6	80.2	176.4	13.19	4.60	17,360	0.0558
C_7H_8	110.3	231.1	13.43	3.90	17,580	0.0558
C_8H_{10}	140.0	284.0	13.60	3.39	17,720	0.0557
C_9H_{12}	....	....	13.72	2.99	.....	.....
$C_{10}H_{14}$	....	....	13.82	2.68	.....	.....
$C_{11}H_{14}$	....	....	13.90	2.42	.....	.....
$C_{12}H_{16}$	....	....	13.98	2.22		
$C_{13}H_{18}$	....	....	14.03	2.04		
$C_{14}H_{22}$	....	....	14.08	1.89		
$C_{15}H_{24}$	....	....	14.13	1.76		
			Olefin Series			
C_5H_{10}	36	96.8	14.69	5.12		
C_6H_{12}	69	156.2	14.69	4.27		
C_7H_{14}	96-99	204.8-210.2	14.69	3.66		
C_8H_{16}	122-123	251.6-253.4	14.69	3.20		
C_9H_{18}	140-142	284-287.6	14.69	2.84		
$C_{10}H_{20}$	175	347.0	14.69	2.56		
$C_{11}H_{22}$	196-197	384.8-386.6	14.69	2.33		
$C_{12}H_{24}$	212-214	413.6-417.2	14.69	2.13		
$C_{13}H_{26}$	233	451.4	14.69	1.97		
$C_{14}H_{28}$	...	....	14.69	1.83		
$C_{15}H_{30}$	247	476.6	14.69	1.71		
			Acetylene Series			
C_5H_8	48-50	118.4-122.0	14.12	5.27		
C_6H_{10}	68-70	154.4-158.0	14.23	4.37		
C_7H_{12}	100-101	212.0-213.8	14.29	3.74		
C_8H_{14}	133-134	271.4-273.2	14.34	3.26		
C_9H_{16}	....	....	14.38	2.89		
$C_{10}H_{18}$	....	....	14.41	2.60		
$C_{11}H_{20}$	210-215	410.0-419.0	14.44	2.36		
$C_{12}H_{22}$	....	....	14.46	2.16		
$C_{13}H_{24}$	....	....	14.48	1.99		
$C_{14}H_{26}$	....	....	14.50	1.85		
$C_{15}H_{28}$	....	....	14.51	1.72		

[27] See Character of Various Fuels for Internal-Combustion Engines by H. T. Tizard and D. R. Pye, published in *The Automobile Engineer*, February, 1921, p. 55.

[28] These values are per cubic inch of mixture at a pressure of 760 mm. (29.92 in.) of mercury and a temperature of 20 deg. cent. (68 deg. fahr.).

TABLE 11—AVERAGE MIXTURE RATIO USED BY 23 CARS UNDER WINTER CONDITIONS.

Condition of Test	Mixture Ratio
Engine Racing	11.9
Engine Idling	12.5
Up 3-Per Cent Grade at 15 m.p.h.	12.5
Up 3-Per Cent Grade at 10 m.p.h.	12.2
Up 3-Per Cent Grade at 3 m.p.h.	12.0
On Level at 15 m.p.h.	12.9
On Level at 10 m.p.h.	12.8
On Level at 3 m.p.h.	12.7
Down 3-Per Cent Grade at 15 m.p.h.	12.8
Down 3-Per Cent Grade at 10 m.p.h.	13.0
Down 3-Per Cent Grade at 3 m.p.h.	13.5

figures show that were equal proportions of each of the 10 compounds of the parafin series mixed in a single fuel the chemically correct mixture-ratio of the average would be incorrect for the lightest or heaviest component by only 1.2 per cent. Similarly such a mixture for the aromatics would be incorrect by 3.5 per cent, for the acetylenes 1.3 per cent and always correct for the olefines.

It will be noticed that the maximum-economy mixtures are leaner and the maximum-power mixtures are richer than the chemically correct mixtures. The presence of exhaust gases, the law of mass action and the limited time available for the completion of the reaction would explain why all three mixtures are not the same. At the present time our knowledge of the relations between these factors is insufficient. In a cylinder of fixed dimensions, as the oxygen occupies a greater volume than the fuel vapor it must be entirely consumed to obtain the maximum power. To accomplish this in the shortest possible time an excess of vapor must be present. In the same way when all the fuel is to be consumed as in the case of maximum economy mixtures, an excess of air must be present.

To indicate what the variation in the mixture ratio with changes in the speed and the load is with present carbureters, several makes of stock carbureters, representing at least 60 per cent of the total number of carbureters in use today, have been tested in the carbureter test-plant at the Bureau of Standards. The results which are presented in Appendix 2 show that there is little agreement among carbureter manufacturers as to the variation of mixture-ratio requirements with changing loads and speeds.

Table 11 gives the average mixture-ratio supplied the engines of 23 average cars tested under winter conditions by the Bureau of Mines.[29] The mixture-ratios were computed from exhaust-gas analysis and indicate that, on the average, cars under winter conditions are using a mixture-ratio ranging from 12 to 13.5, corresponding more nearly to maximum power than maximum economy.

Mixing and Vaporization

Insufficient fuel and air mixing is probably the source of the greatest fuel waste today. Poor distribution among cylinders and the need for over-rich mixtures when starting and accelerations are the result of insufficient mixing. Minute and thorough subdivision of the fuel is the solution of the mixing problem. The difficulties involved in attaining thorough mixing are realized when it is appreciated that (*a*) when liquid gasoline is injected into an airstream probably not more than a small percentage is ever vaporized before entering the engine cylinder except when the air in the manifold is heated; (*b*) a cube of liquid gasoline 0.1 in. on a side is all that is required to be mixed with a cube of air 2.1 in. on a side; (*c*) when the cube of gasoline is evaporated the vapor occupies a cube 0.6 in. on a side; and (*d*) from 0.1 to 1.0 sec. elapses from the time the liquid fuel leaves the carbureter jet until it is ignited within the cylinder (See Figs. 2 and 3). Subdivision of the fuel may be accomplished in two ways, (*a*) by vaporization or change in state, and (*b*) by minute subdivision of the liquid or atomization.

Vaporization of the liquid fuel gives the most minute subdivision attainable. To vaporize the fuel a definite quantity of heat must be supplied per pound. Table 12 gives a number of values for the latent heat of vaporization and specific heats of the liquid for gasolines and some pure compounds found in liquid fuels. Variation in the latent heat values are to be expected from the known variation in the composition of gasolines. Vapor-

TABLE 12—LATENT HEATS OF VAPORIZATION

Fuel	Latent Heat of Evaporation, B.t.u. per lb.	Authority
Gasolines		
Aromatic free	133.0	Ricardo
"A"	142.0	Ricardo
"B"	140.0	Ricardo
"C"	135.0	Ricardo
"D"	132.0	Ricardo
"E"	133.0	Ricardo
"F"	134.0	Ricardo
"H"	145.0	Ricardo
Gasoline	100.2	Redwood
Heavy Fuels		
Heavy Aromatic	136.0	Ricardo
Kerosene	108.0	Ricardo
Kerosene	105.4	Redwood
Parafin Series		
Hexane, 80 per cent	156.0	Ricardo
Hexane	210.0	Sorell
Heptane, 97 per cent	133.0	Ricardo
Decane at 159.45 deg. cent. (318.65 deg. fahr.)	109.5	Longuinine
Aromatic Series		
Benzene, pure	172.0	Ricardo
Benzol	169.0	Marks' Handbook
Benzol at 0 deg. cent. (32 deg. fahr.)	196.0	Regnault
Benzol at 100 deg. cent. (212 deg. fahr.)	238.0	Regnault
Benzol at 210 deg. cent. (410 deg. fahr.)	278.0	Regnault
Toluene, 99 per cent	151.0	Ricardo
Xylene, 91 per cent	145.0	Ricardo
Naphthene Series		
Cyclohexane, 93 per cent	156.0	Ricardo
Hexahydrotoluene, 80 per cent	138.0	Ricardo
Hexahydroxylene, 60 per cent	133.0	Ricardo
Alcohol Group		
Ethyl Alcohol, 98 per cent	406.0	Ricardo
Ethyl Alcohol at 78 deg. cent. (172 deg. fahr.)	372.0	Schall
Methyl Alcohol at 64.5 deg. cent. (148 deg. fahr.)	482.0	Wirtz
Acetone	239.0	Ricardo
Acetone	233.0	Marks' Handbook
Acetone at 20 deg. cent. (68 deg. fahr.)	247.0	Regnault
Miscellaneous		
Carbon Bisulphide 50 per cent Aromatic free 50 per cent by volume	145.0	Ricardo

[29] See Gasoline Losses Due to Incomplete Combustion in Motor Vehicles by A. C. Fieldner, A. A. Straub and G. W. Jones, published in *Journal of Industrial and Engineering Chemistry*, vol. 13, p. 51.

ized fuel occupies over 200 times the volume of the liquid fuel before vaporization, and in an explosive mixture the vapor volume represents from 1 to 2.5 per cent of the total volume of the charge. Table 10 gives the vapor volumes of some compounds.

Complete vaporization of the fuel would decrease the volume of air which could be admitted to a fixed cylinder; hence, the power of the engine by about 2 per cent. On the other hand, the cooling of the charge caused by such evaporation, if no heat were supplied the air from external sources, would contract the air by some 7 per cent, thus increasing the power output by this amount. Thus vaporization of the fuel causes a net increase in the power output, and the heating of the charge in the manifold, a decrease. The temperature required for complete vaporization is at least equal to the temperature at which the vapor pressure of the fuel equals its partial pressure in the explosive mixture. If this is more than about 20 deg. fahr. above that of the entering air, a net loss of air volume will result.

Sufficiently fine atomization of the liquid fuel at the carbureter jet and subsequent vaporization within the cylinder during compression would accomplish the same result as vaporization without the attendant loss of air volume and hence power output. Very little information is available as to the formation of minute liquid particles from a solid liquid stream, but very suggestive reading can be found in the article on Capillary Action by James Clerk Maxwell and Lord Rayleigh in the 11th Edition of the Encyclopedia Britannica. There have been no methods for the measurement of the size of particles applied to the discharge from carbureters and no quantitative data are available on the subject.

Charge Quantity Control

Three methods have been used to control the quantity of explosive charge used, namely, reducing (*a*) the manifold pressure but not the volume of the charge drawn from it which is the usual throttle control; (*b*) the effective time-interval of inlet-valve opening, but not the manifold pressure or what is known as variable inlet-valve timing; and (*c*) the weight of the *combustible* charge but not the cylinder charge weight or the stratification and direct fuel-injection method. In the first method the power required to pump the cylinder charge from the manifold to the exhaust pressure increases with a reduced load, thus reducing the economy with the load. At 20 per cent full load the loss in economy may amount to about 20 per cent.[30] Exhaust-gas dilution also increases with a reduction in the load and thus reduces the leanness of the mixtures which will explode. When variable inlet-valve timing is used there is no increase in the "pumping loss" with a reduction in the load, and the exhaust-gas dilution increases with a reduction in the load in the same manner as when charge throttling is used. However, mechanical complications are introduced. Results on a test of an engine using a late-closing inlet-valve[31] show that at a little less than half-load the fuel-consumption was about 50 per cent less than that attained when using fixed valve-timing and the usual throttle control. In the case where charge stratification is relied on entirely, "pumping loss" is entirely eliminated. As yet no commercial application of direct-injection engines has been made to automobiles. Mr. Ricardo[32] also gives results from tests of an engine using stratified charge and fuel throttling for reduced loads. The results show a remarkably constant thermal efficiency of from 30 to 35 per cent from full load to about 0.15 load.

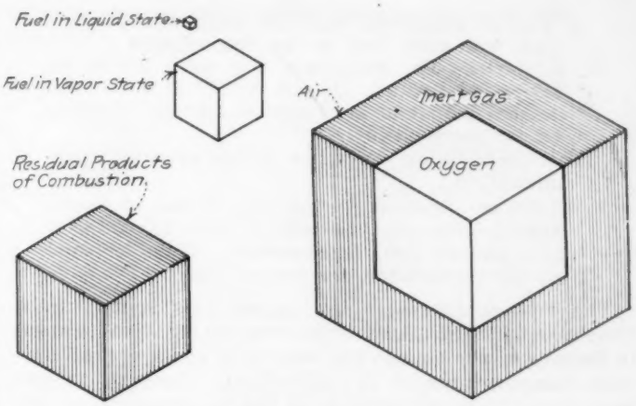

Fig. 2—Relative Volume of Gases in the Engine Cylinder at Full Load

The chemical energy of the explosive mixture supplied the cylinder is transformed into gas pressure by (*a*) an increase in temperature of the gases within the cylinder resulting from heat added during combustion and (*b*) a difference in specific volume of the gases before and after combustion, due to a change in the number of molecules during combustion. Except in the case of Diesel engines which will not be considered here, combustion is usually started by the passage of an electric spark through the explosive mixture. Detailed information on ignition properties will be found in the following papers:

J. D. Morgan—Principles of Electric-Spark Ignition in Internal-Combustion Engines, published by Crosby Lockwood & Co.
An excellent general discussion of the subject

C. C. Paterson and N. R. Campbell—Some Characteristics of the Spark Discharge and Its Effects in Igniting Explosive Mixtures, published in *Proceedings of the Physical Society* (London) vol. 31, p. 168
A detailed account of researches at National Physical Laboratory

A. P. Young and H. Warren—The Process of Ignition, *Automobile Engineer*, March, 1920, p. 115

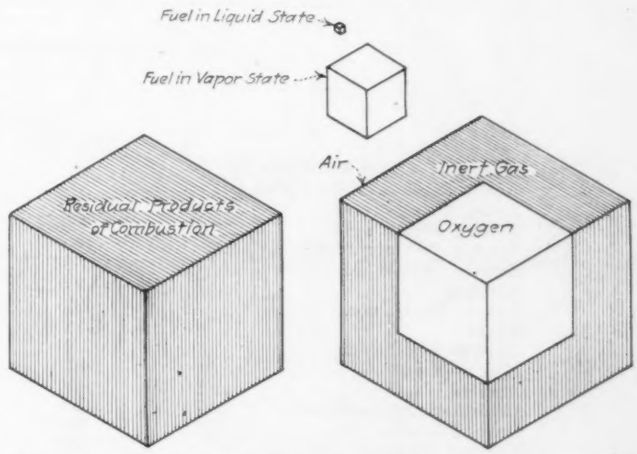

Fig. 3—Relative Volume of Gases in the Engine Cylinder at a 20-Per Cent Load

[30] See Appendix 3 to this paper.

[31] See Some Possible Lines of Development in Aircraft Engines by H. R. Ricardo, published in *Aeronautical Journal* (London), March, 1921, p. 143.

[32] See *Aeronautical Journal* (London), March, 1921, p. 140.

A general discussion from the engineer's point of view, with many data on sparking voltages

W. S. Gorton—The Subsidiary Gap as a Means for Improving Ignition. Report No. 57 of the Fourth Annual Report of the National Advisory Committee for Aeronautics

This discusses the operation of the so-called spark intensifiers

F. B. Silsbee—Ignition Work at the Bureau of Standards. *Automotive Industries*, June 12, 1919, p. 1294, and the Fifth Annual Report of the National Advisory Committee for Aeronautics

The voltage necessary to produce this spark varies from about 2000 to 15,000 volts,[33] increasing with increase in density of the charge and length of spark-gap at constant temperatures of the electrodes. Recently it has been found that an increase in the temperature of the spark-plug electrodes decreases materially the sparking voltage required. This decrease may amount to as much as 50 per cent. It has been shown[34] that when a truly explosive charge surrounds the spark-gap any spark passing the gap will ignite the charge. It has not been shown, however, that this is true if the explosive charge be near the limit of inflammability, from either incomplete vaporization or dilution. The results of the experiments on the explosive limits of mixtures indicate that the character of the spark discharge has a decided effect on ignition. The effect of spark characteristics on the ignition of poor mixtures needs further attention.

Mention should be made of "spontaneous" or "autoignition" temperatures. Spontaneous-ignition temperature is usually thought of as the temperature at which a given mixture ignites without ignition being supplied at any point from an outside source. Spontaneous ignition may occur in an engine cylinder with certain fuels and compression-ratios. When an engine is operating certain metal parts, such as spark-plug electrodes and valves, or carbon deposits, remain at a higher temperature than the average temperature of the charge. If the temperature of any of these surfaces is sufficiently above the ignition point of the fuel so that it can supply enough heat to raise a portion of the charge to the spontaneous-ignition temperature, ignition will take place even though the average temperature of the gas is below its spontaneous-ignition temperature. The lower the ignition temperature of the gas, the smaller the rise in temperature necessary to be produced in this way. Hence, ignition of this sort will occur in the engine at average mixture temperatures lower than the spontaneous-ignition temperatures of the fuel, but these average mixture temperatures will vary under the same cylinder conditions with different fuels in much the same manner as the true spontaneous-ignition temperatures of the fuels. It has been shown[35] that the spontaneous-ignition temperature for hydrogen at least is materially raised by the dilution of the explosive mixture by an inert gas. Some values for spontaneous-ignition temperatures are given in Table 13.

Assuming the usual pressure-volume and temperature relations, the increase in the average gas temperature and therefore the cylinder pressure is limited by four factors, (*a*) the amount of heat liberated by the combustion of the fuel per unit volume of combustible mixture, allowing for heat absorbed in the dissociation of the products of the combustion, (*b*) the heat capacity of the gases contained in the cylinder at the end of the preceding exhaust stroke, (*c*) the rate of heat loss from the hot gases, and (*d*) the rate at which the mixture burns.

Heat of Combustion

The heats of combustion of nearly all of the constituents of gasoline have been measured. Some values for these heats of combustion are given in Table 10 in terms of British thermal units per pound of fuel and British thermal units per cubic inch of combustible mixture of several mixture strengths. The effects of dissociation on the effective heats of combustion will not be considered here, although it is of great importance in determining the effective heating value of the fuel. An excellent treatment by Tizard and Pye has been published recently in *The Automobile Engineer*.[36]

There is considerable doubt as to the accuracy of the available specific heat measurements of gases at high

[33] See Report No. 54 of the Fifth Annual Report of the National Advisory Committee for Aeronautics and Process of Ignition by A. P. Warren and H. Young, published in *The Automobile Engineer*, March, 1920, p. 115.

[34] See Some Characteristics of the Spark Discharge and Its Effects in Igniting Explosive Mixtures by C. C. Paterson and N. R. Campbell, published in *Proceedings of the Physical Society* (London), vol. 31, p. 168.

[35] See Ignition Temperatures of Gaseous Mixtures by K. G. Falk, published in *Journal of the American Chemical Society*, vol. 29, p. 1536.

[36] See Character of Various Fuels for Internal-Combustion Engines by H. T. Tizard and D. R. Pye, published in *The Automobile Engineer*, February, 1921, p. 55, March, 1921, p. 98, and April, 1921, p. 134, and Specific Heat of the Working Fluid in Internal-Combustion Engines by D. R. Pye, published in *The Automobile Engineer*, February, 1920, p. 57.

TABLE 13—SPONTANEOUS-IGNITION TEMPERATURES

Fuel	Ignition Temperature In Oxygen deg. cent.	In Oxygen deg. fahr.	In Air deg. cent.	In Air deg. fahr.	Authority
Gasoline, Anglo-American Oil Co., Ltd.	...	...	392	738	Moore
Kerosene, Anglo-American Oil Co., Ltd.	...	...	367	693	Moore
Xylol, Commercial	484	893	...	...	Moore
Toluol, 90 per cent	516	961	...	...	Moore
Benzol, 100 per cent	566	1051	...	...	Moore
Ethyl Alcohol	395	743	518	964	Moore
Alcohol	510-515	950-959	595-600	1103-1112	Dixon
Ether, Methylated	190	374	347	657	Moore
Ether	235-240	455-464	560-580	1040-1076	Dixon
Carbon Bisulphide	119	246	...	...	Moore
Nitrobenzene	432	810	...	...	Moore
Anilene	550	1022	...	...	Moore
Benzene, Crystallisable	620	1148	...	...	Moore
Pure Toluene	596	1109	...	...	Moore
Normal Hexane	287	549	...	...	Moore
Heptane	281	538	...	...	Moore
Pentane	550	1022	560-570	1040-1058	Dixon

TABLE 14—SPECIFIC HEATS AT A CONSTANT VOLUME OF SOME GASES USED AS THE WORKING FLUID IN INTERNAL COMBUSTION ENGINES[37]

Temperature Range deg. cent.	Temperature Range deg. fahr.	Gases: Carbon Dioxide	Gases: Nitrogen	Gases: Water Vapor	Authority
0	32	0.152	0.178	0.352	Holborn, Scheel and Henning
0- 200	32- 392	0.174	0.180	0.361	Holborn, Scheel and Henning
0- 400	32- 752	0.189	0.182	0.366	Holborn, Scheel and Henning
100- 500	212- 932	0.188	0.192	0.348	Tizard and Pye
0- 600	32-1,112	0.200	0.184	0.375	Holborn, Scheel and Henning
0- 800	32-1,472	0.207	0.186	0.384	Holborn, Scheel and Henning
0-1,000	32-1,832	0.212	0.188	0.394	Holborn, Scheel and Henning
100-1,000	212-1,832	0.217	0.196	0.386	Tizard and Pye
0-1,200	32-2,192	0.217	0.190	0.403	Holborn, Scheel and Henning
0-1,400	32-2,552	0.224	0.192	0.412	Holborn, Scheel and Henning
100-1,500	212-2,732	0.229	0.204	0.425	Tizard and Pye
100-2,000	212-3,632	0.238	0.213	0.468	Tizard and Pye
100-2,500	212-4,532	0.247	0.222	0.539	Tizard and Pye
100-3,000	212-5,432	0.249	0.234	0.623	Tizard and Pye

AVERAGE VALUES BETWEEN 20 AND 100 DEG. CENT. (68 AND 212 DEG. FAHR.) FOR AIR ACCORDING TO HOLBORN, SCHEEL AND HENNING

Pressure, lb. per sq. in.	Specific Heat at a Constant Volume
14.7	0.172
200.0	0.176
400.0	0.180
600.0	0.184
800.0	0.188
1,000.0	0.192
1,200.0	0.196
1,400.0	0.200

[37] The figures given are average values for the range stated. The values attributed to Tizard and Pye are taken from an article by them entitled Character of Various Fuels for Internal-Combustion Engines which was published in *The Automobile Engineer*, February, 1921, p. 56; the others are from Wärmetabellen by L. Holborn, K. Scheel and F. Henning.

temperatures and pressures. Tizard and Pye, who have examined the experimental results with care, believe the values obtained by Pier and Bjerrum are very good. The values quoted by them are given in Table 14, together with values obtained by Holborn and Henning. It will be noted that the results quoted show a decided increase in specific heat with increase in temperature and pressure.

The rate of heat loss from the gases during combustion to the cylinder walls is not known. It is probably very high but of short duration. Measurements of the amount of heat entering the jacket water are of little value for this purpose. There is very little reliable information on the rate at which energy is liberated from a combustible mixture. This rate is not necessarily that with which the flame passes through a mixture. Some idea of the rate of heat liberation during combustion can be gained from Fig. 4. The data presented in this plot were obtained with the high-speed indicator developed at the Bureau of Standards and published values of specific heat. It indicates what variations in the rate of burning are to be expected.

The number of factors believed to affect the rate of burning is large, probably because we know so little about it and cannot as yet separate the important from the unimportant factors. Some of these will be enumerated but not discussed because of lack of information. They are (*a*) temperature and pressure at ignition, (*b*) point of stroke at which ignition occurs,[38] (*c*) number of points of ignition, (*d*) mixture ratio, (*e*) shape of combustion-chamber, (*f*) fuel, (*g*) turbulence, (*h*) auto-ignition temperature of fuel and (*i*) detonation tendency. The phenomena related to what is usually termed "detonation" and probably more fittingly termed by Dr. Gibson "flame slap" are discussed in Appendix 5.

The ratio of the volume of the charge after combustion to the volume before combustion at the same temperature and pressure is given for about 10 of each of the principal series of compounds occurring in engine fuels in Table 10. The cylinder pressures after combustion will be increased by an amount proportional to the increase

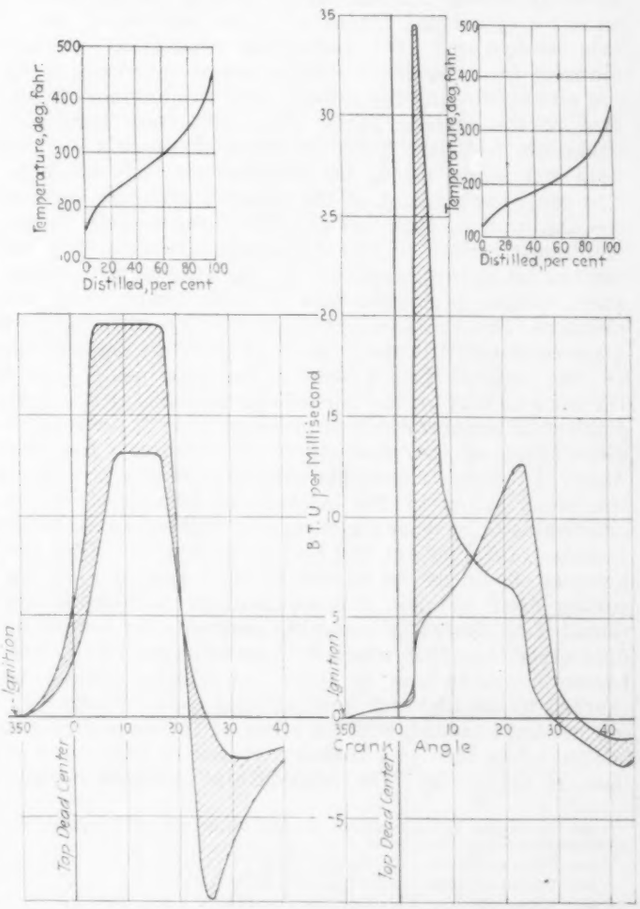

FIG. 4—CURVE SHOWING THE RATE OF HEAT LIBERATION DURING COMBUSTION

[38] See Recent Automobile Research at the Bureau of Standards by Herbert Chase, published in *Automotive Industries*, April 7, 1921, p. 750.

TABLE 15—TESTS OF A FRANKLIN TRANSMISSION ON DIRECT DRIVE

Speed, r.p.m.	Power Input, b.hp.	Efficiency, per cent.
800	1	80.0
800	2	85.0
800	4	95.0
800	6	97.0
800	16	97.0
1,200	2	84.0
1,200	4	92.0
1,200	6	95.0
1,200	8	96.0
1,200	10	97.0
1,200	14	98.0
1,200	18	98.0
1,500	2	80.0
1,500	4	89.0
1,500	6	93.0
1,500	8	95.0
1,500	14	97.0
1,500	18	97.5

in specific volume given in the table. This increase in pressure due to the presence of a greater number of molecules increases with the molecular weight of the fuel.

Gas Pressure Transformation Loss

The transformation of gas pressures into crankshaft torque in a cylinder, reciprocating piston and crank mechanism is fundamentally an intermittent process. It is made continuous either by the use of a reservoir of energy such as a flywheel or by the multiplication of elements acting intermittently, that is, the addition of working cylinders. There are four sources of loss in this mechanism: (*a*) incomplete expansion, (*b*) heat transfer from the gases under pressure, (*c*) work of filling and exhausting the cylinder and (*d*) mechanical friction of the moving parts. The loss from incomplete expansion is usually given in terms of air as a working fluid and is one minus the so-called air-cycle efficiency. The usual computation of the air-cycle efficiency involves the assumptions that (*a*) the last three sources of loss mentioned earlier in this paragraph are zero, (*b*) the combustion is instantaneous, (*c*) the specific heat at constant volume is independent of both temperature and pressure, (*d*) the specific volume of the working fluid after combustion is the same as it is before combustion, (*e*) the ratio of specific heats of the unburned charge is the same as that for the burned charge and both are independent of temperature and pressure and (*f*) there is no dissociation of the products of combustion. Any loss incurred through incomplete expansion is directly due to the imperfection of the mechanism, because it is impracticable to increase the expansion without an excessive increase in the weight and size of the engine. This loss however should not be altered by the losses or gains resulting from the last five assumptions just made, nor should it be altered by assuming constants for a working fluid other than that which it is actually possible to use. Losses or gains due to these assumptions should be charged to the fuel and working fluid used. To be sure, our present knowledge of the effect of these assumptions is incomplete but it is sufficient to tell us that none of them is negligible. The relationships involved in each can and should be determined in order that the status of any process of combustion under pressure can be truly interpreted. Some recent preliminary determinations of the ratio of specific heats at atmospheric temperature and pressure of a particular sample of explosive mixture taken from an engine, gave a value of 1.36 and a particular sample of exhaust gas gave 1.34. Corrections for the higher temperatures of the exhaust gases would probably reduce the latter figure below 1.30.

The loss due to the heat transferred from the working fluid to the cylinder walls is directly chargeable to the type of mechanism used. No good values of this loss have been determined but they may range from 15 to 25 per cent of the total heat in the fuel. The work lost in filling and exhausting the cylinder includes (*a*) a direct loss, negative piston-pressures as given by the lower loop of the indicator card, and (*b*) an indirect loss, the loss in the weight of the cylinder charge due to throttling, gas heating, etc., usually included under the term volumetric efficiency, which is one of the factors governing the size of the engine used to give a definite performance, or the maximum power output of a given engine. Any reduction in the maximum power with a constant mechanical loss involves a loss in brake efficiency, and if a larger engine is required to produce the same power, both the mechanical losses and the power required to carry the engine are increased as the size of the engine is increased. The losses due to negative piston-pressures increase with reduction in load and their magnitude is indicated in Appendix 3. Losses due to a reduction of the cylinder charge vary with valve-timing, valve design and engine speed. They may vary from 50 to less than 5 per cent. The losses due to mechanical friction of the moving parts vary from 10 to 40 per cent with different engines and increase so materially with speed as to raise some doubt as to the possible fuel-economy of small high-speed engines. (See Appendices 3 and 6.)

The transformation of crankshaft torque into thrust at the rear wheels involves three factors; (*a*) transmission efficiency, (*b*) universal-joint efficiency, and (*c*) rear-end efficiency. All of these factors are affected to a marked degree by the kind of lubricant used and its method of application.

Power Transmission Efficiency

Considering the system as a unit the efficiencies may vary from 50 to 85 per cent according to Riedler.[39] The value given by the Automobile Engineer's Handbook, 1920, London, is 85 per cent. Lewis P. Kalb[40] considers 90 per cent to be a closer value. Universal-joint efficiencies according to C. W. Spicer[41] range from about 92 to nearly 100 per cent when transmitting power in excess of 5 hp. At lower powers the efficiency may drop as low as 80 per cent. These data include results with angles of from 2 to 12 deg. with forks in the same plane and at 90 deg. Mr. Spicer makes the following statement:

> Between 10 and 100 per cent of full load, the efficiency is above 99 per cent for all angles less than 7 deg.

The efficiency of the gearbox according to tests made by Worby Beaumont is from 70 to 90 per cent on direct drive. Tests of a Franklin transmission described in *The Horseless Age*[42] give the results contained in Table 15 on direct drive. C. M. Allen[43] finds efficiency of a worm-gear axle varies from 70 to 85 per cent with power inputs of from 2 to 8 hp. reaching 90 per cent for higher inputs. With a bevel-gear axle the efficiencies ranged

[39] See Scientific Determination of the Merits of Automobiles by A. Riedler.

[40] See TRANSACTIONS, vol. 14, part 2, p. 69.

[41] See TRANSACTIONS, vol. 10, part 1, p. 247.

[42] See *Horseless Age*, Feb. 12, 1908, p. 161.

[43] See *Transactions of the American Society of Mechanical Engineers*, vol. 40, p. 101.

from 95 to 98 per cent with inputs of from 2 to 8 hp. and were above 98 per cent for higher inputs.

From the point of view of the power requirements of cars it is believed that (*a*) the car performance demanded by the average driver is not unreasonable and (*b*) greater fuel-economy could be attained by a sound far-sighted good-roads program through possible reduction of car-weight and also road-resistance.

From the point of view of power development and its delivery to the road it is believed that (*a*) the greatest gain in fuel-economy would result from an effort spent on the preparation of the unburned charge under all conditions of temperature, engine speed and load, first from a thorough mixing of the air and fuel and second from a correct variation of the fuel and air proportions; (*b*) the reduction of the mechanical friction losses, possibly through a change of engine speed and size, will increase the fuel-economy at part throttle without any sacrifice in performance and (*c*) the closer study of the processes of combustion will make possible a rational basis for the statement of the ultimate engine efficiency and a clearer conception of the value of different fuels.

APPENDIX 1.

Influence of Air and Fuel Proportions Upon Engine Efficiency and Power[44]

The carbureter exists to proportion air and fuel so that the engine can deliver its maximum power or attain its maximum efficiency. Experiments to determine what these proportions should be have been made usually upon multi-cylinder engines. Faulty distribution influences the results thus obtained since it necessitates an excess of fuel being supplied to some cylinders in order that the other cylinders can receive sufficient fuel for satisfactory operation. These results are, however, of immediate value as they show what proportions the carbureter must furnish to cope with the faults of existing induction systems and yet give satisfactory engine operation. Determining these proportions with a one-cylinder engine as has been done by Mr. Ricardo eliminates the distribution problem and results thus obtained fix values that can be approached by the multi-cylinder engine as its distribution improves.

The chemical combining proportion of air and a given fuel is a fixed quantity. In practice, a lower air-fuel ratio usually gives greater power and a higher air-fuel ratio greater economy. One reason for this is the lack of an intimate mixing of the air and the fuel. Excess fuel makes certain that all the oxygen of the air is brought into contact with sufficient fuel for combination and since the engine power is limited by the amount of air that can be utilized in a unit time this insures the attainment of the maximum power. Supplying excess air tends to make certain that all the fuel is intimately associated with sufficient air to insure its combustion and thus to attain the maximum economy. In the first case, the maximum output of the engine is desired and in the second case the maximum output from the energy of the fuel.

Investigators are in fairly close agreement as to the air-fuel proportions for maximum power, finding ratios of from 11 to 1 to 13 to 1 best in this regard for ordinary gasoline. A recent series of tests at the Bureau of Standards has shown that with an aviation engine having compression ratios of 5:3, 6:3, 7:3, and 8:3, the maximum power was obtained with air-fuel ratios of from 13 to

[44] Contributed by S. W. Sparrow, M.S.A.E.—Mechanical engineer, Bureau of Standards, Washington.

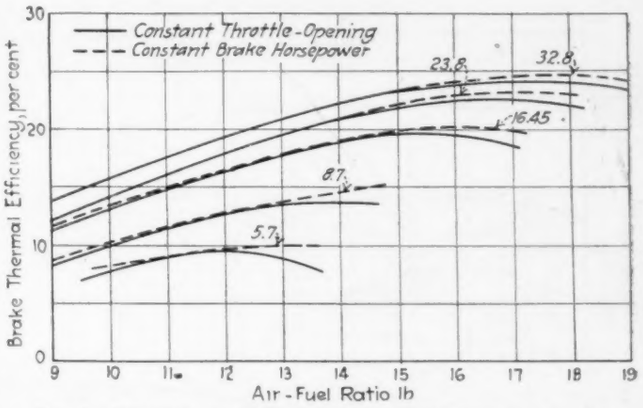

Fig. 5—Relation of Brake Thermal Efficiency to the Air-Fuel Ratio

1 and 14 to 1 with air densities of from 0.025 to 0.075 lb. per cu. ft. This was, however, with aviation gasoline, a more volatile product than the commercial fuel.

Maximum economy is the condition with which the automobile engineer is most concerned. It would therefore be expected that much reliable information would be

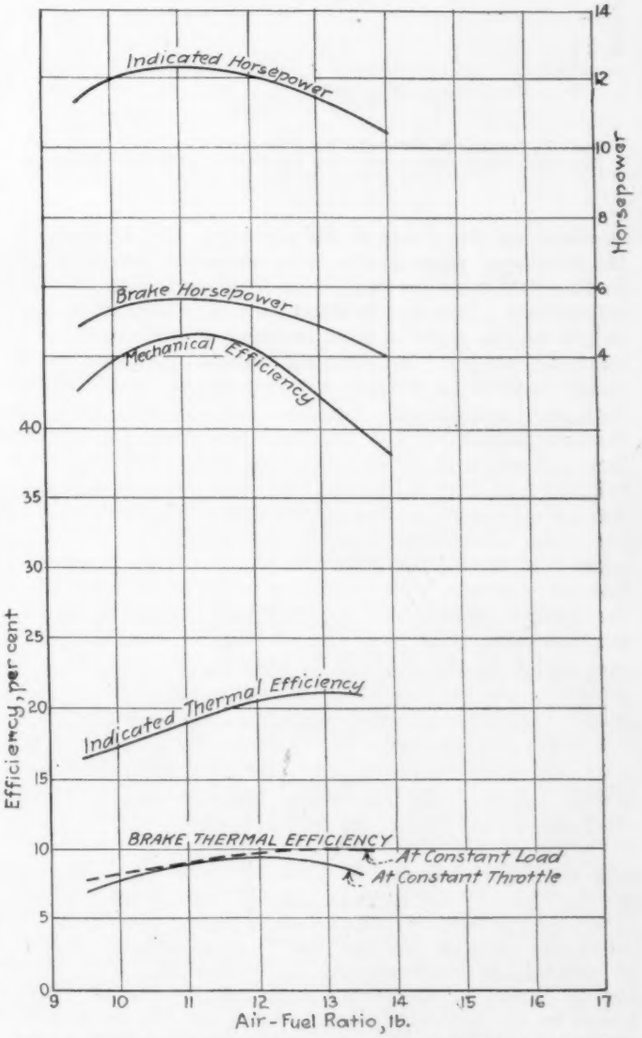

Fig. 6—Relation between the Air-to-Fuel Ratio and the Indicated and Brake Horsepowers and the Mechanical, Indicated Thermal and Brake Thermal Efficiencies

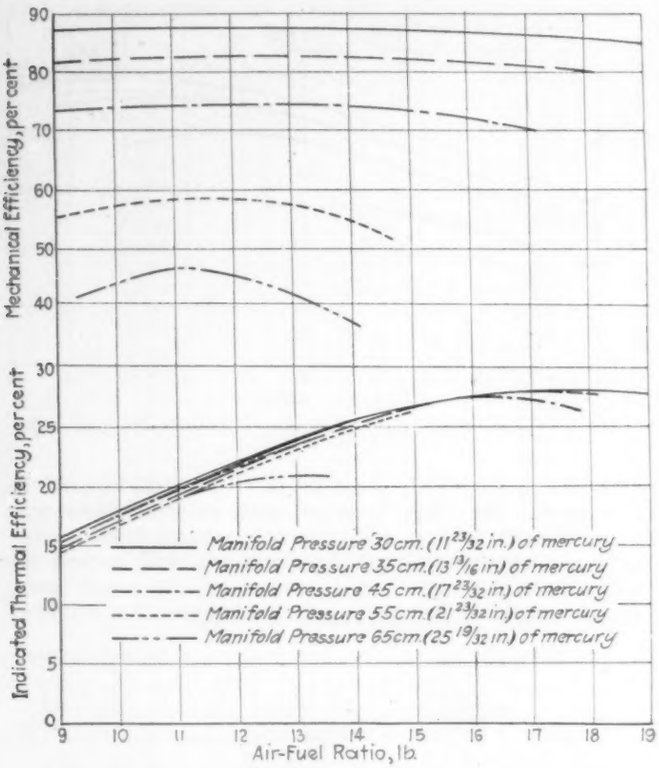
Mechanical Efficiency, per cent
Indicated Thermal Efficiency, per cent
Air-Fuel Ratio, lb
Manifold Pressure 30 cm. (11 23/32 in.) of mercury
Manifold Pressure 35 cm. (13 49/64 in.) of mercury
Manifold Pressure 45 cm. (17 23/32 in.) of mercury
Manifold Pressure 55 cm. (21 23/32 in.) of mercury
Manifold Pressure 65 cm. (25 19/32 in.) of mercury

FIG. 7—RELATION BETWEEN THE MECHANICAL AND INDICATED THERMAL EFFICIENCIES AND THE AIR-FUEL RATIO FOR DIFFERENT MANIFOLD DEPRESSIONS

available on this phase of the problem. On the contrary, the results of some of the most extensive investigations in this field seem to have been incorrectly analyzed and interpreted. Hence it is worthwhile to comment at some length on this error of interpretation to prevent its being made by others. In studying engine operation at reduced loads with various air-fuel ratios, the condition that was maintained constant has usually been the throttle position or the manifold pressure. Results are then plotted in a family of curves, such as are given in full lines in Fig. 5, which show the relation of brake thermal efficiency or fuel-consumption in pounds of fuel per brake horsepower-hour to air-fuel ratio. It will be noted that the highest efficiency shown by the upper full-line curve occurs with a mixture ratio of 17 to 1, while the highest shown by the lower full-line curve is at a mixture ratio of 12 to 1. As 33 b.hp. is obtained in one case and 6 in the other it is natural, but incorrect, to conclude that for maximum efficiency the air-fuel ratio should vary from 17 to 1 to 12 to 1 with this change in the brake horsepower. What is wrong? The curves show the mixture proportions that will give maximum efficiency at a constant throttle-opening. They do not show the mixture-ratio at which a *given power* can be developed at maximum efficiency, which is the information desired. Fig. 6 has been prepared to make this point clear. In addition to the efficiency at a constant throttle the brake horsepower is plotted. Adding to the latter the friction horsepower, which would not change appreciably with the change in the mixture-ratio, gives the indicated horsepower. Dividing the brake horsepower by the indicated horsepower gives the mechanical efficiency, and by dividing the brake thermal efficiency by the mechanical efficiency the indicated thermal efficiency is obtained. The last named efficiency is the percentage of the energy of the fuel that is converted into work and it is greatest with an air fuel ratio of 13.5 instead of 12, although higher efficiency would be obtained at a much leaner mixture if the engine would operate regularly on such a mixture. In developing a given brake horsepower the friction horsepower and hence the mechanical efficiency will be independent of mixture ratio. To maintain a constant brake horsepower with any change in the mixture proportions the throttle must be opened slightly for mixtures other than those giving the maximum power. The magnitude of this effect is too small to be considered here but neglecting it makes the proportions chosen for the maximum efficiency somewhat richer than the correct ones. Hence multiplying the indicated thermal efficiency by the constant mechanical efficiency for a given brake horsepower, gives the brake thermal efficiency obtained with various air-fuel ratios when developing this power. The dotted line shows the result obtained in this instance.

In the manner just described, the mechanical and indicated thermal efficiencies for all the conditions of Fig. 5 have been plotted in Fig. 7. From these values the dotted curves of Fig. 5, giving the brake thermal efficiencies at a constant power, have been derived. It will be obvious from the foregoing that for a *given power development* at less than full throttle the maximum indicated and brake thermal efficiencies are obtained with the same mixture proportions and the determination of either as sufficient.

A consideration of the thermal efficiencies of Fig. 7 shows in nearly every instance an increase with one in the air-fuel ratio until the mixture becomes too lean for steady running of the engine. A value of 16 to 1 appears best for all loads except the two lowest and these would require richer mixtures for steady running. Such work as has been done on this subject at the Bureau of Standards has given similar results. The important thing to be noted is that the efficiency with any proportions with which the engine will operate is independent of the power developed. The same conclusion seems to have been reached by Mr. Ricardo, judging from the following statement:[45]

> I carried out a very large number of tests on about 40 different fuels to ascertain the relation between mixture strength, power and economy. Except for insignificant variations the characteristic efficiency and power obtained by gradually weakening the mixture is the same for all fuels and at all compressions excepting alcohol.

Failure of the engine to operate properly at very low loads with mixtures as lean as those giving maximum efficiency at greater loads seems to be due to dilution by the residual products of combustion. An analysis of this influence with experimental evidence to support this viewpoint has been given in the main portion of the paper and need not be repeated here.

It is concluded therefore that for present types of automobile engine the maximum power is obtained with air-fuel ratios of from 11 to 1 to 13 to 1 and the maximum efficiency at ratios in the neighborhood of 16 to 1, if the engine will operate regularly with such mixtures. Where dilution by the products of combustion necessitates richer mixtures the maximum efficiency is attained with the leanest mixture at which the engine will operate regularly.

[45] See *Automotive Industries*, Feb. 24, 1921, p. 460.

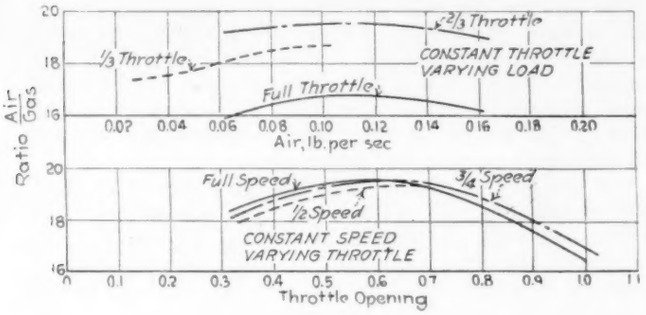

Fig. 8

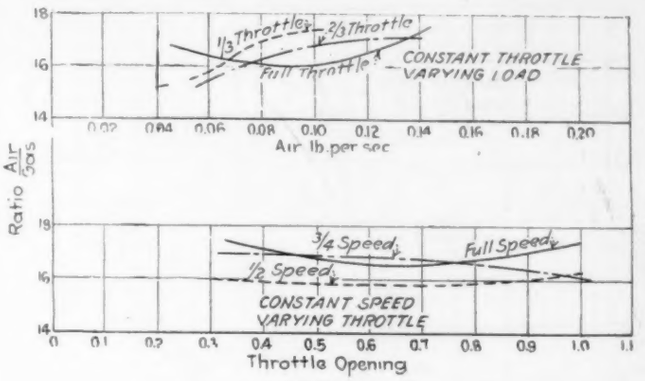

Fig. 9

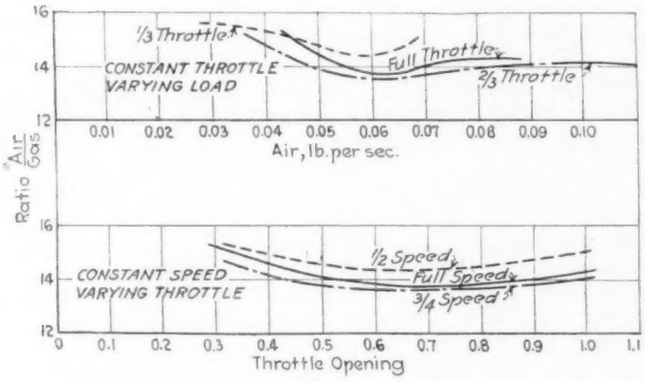

Fig. 10

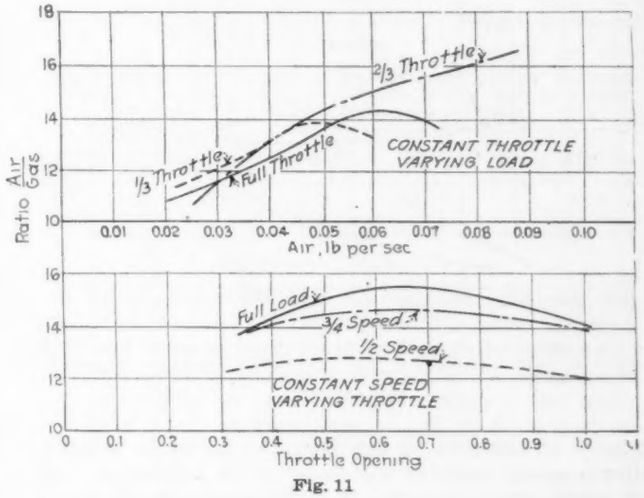

Fig. 11

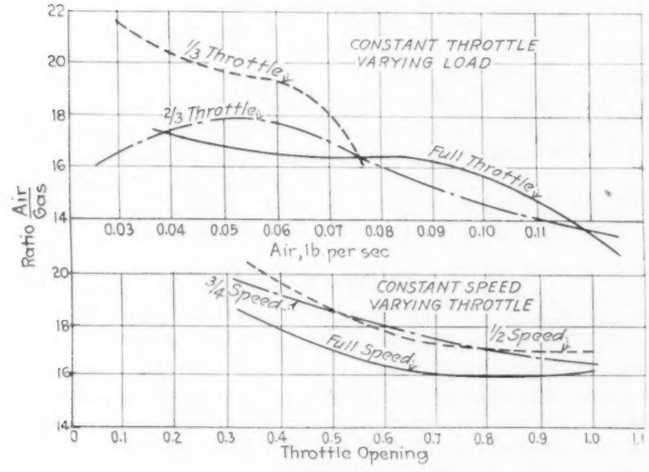

Fig. 12

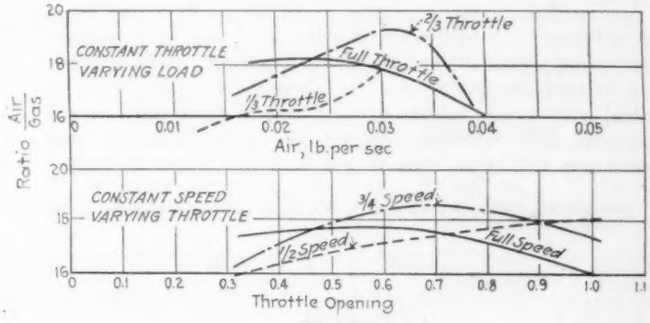

Fig. 13

FIGS. 8 TO 13—MIXTURE RATIOS WITH CHANGING LOAD FOR THREE CONSTANT-THROTTLE POSITIONS AND THE VARYING RATIOS OBTAINED AT A CONSTANT SPEED WITH VARYING-THROTTLE POSITIONS

APPENDIX 2

METERING CHARACTERISTICS OF SIX STOCK CARBURETERS[43]

As any wide departure of the mixture ratio from that corresponding to the maximum economy with a changing load on the engine may mean a serious waste of fuel, the load-mixture characteristics of several widely used carbureters are of interest. It might be assumed that since the pressure reduction causing fuel flow depends on the velocity, at a constant density, through the venturi in the normal type of carbureter, the gasoline discharge, and consequently the mixture ratio, would be determined solely by the weight of air used per second, or by the engine load. It is to be remembered, however, that a given weight of air may be used under very many different combinations of throttle position and manifold depression, corresponding with different relations of torque and speed of the engine. Now experiment shows that with the usual location of the throttle, throat suction and consequently mixture ratios are affected not only by quantity of air passing but by the degree of opening of the throttle itself.

With this effect in mind, mixture ratios were determined for six widely used carbureters for various rates of flow, each at several relations of throttle position and manifold depression. The resulting mixture ratios with changing load for three constant throttle-positions for these carbureters are shown in the upper portion of Figs. 8, 9, 10, 11, 12 and 13, respectively.

Since, in automobile operations, there seems to be a

[43] Contributed by R. L. Wales, Carbureter laboratory, Bureau of Standards, Washington.

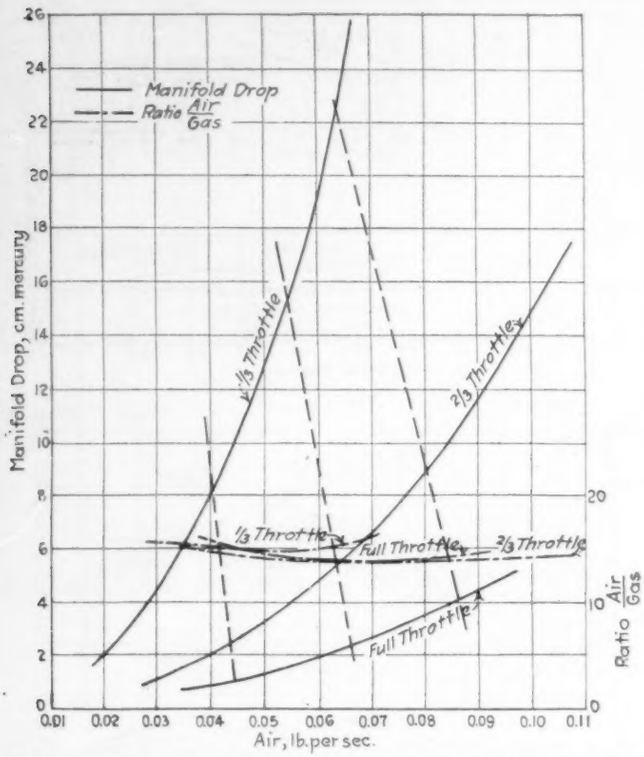

FIG. 14 — RELATION BETWEEN MANIFOLD DEPRESSIONS AND THE WEIGHT OF AIR PER SECOND FOR DIFFERENT THROTTLE POSITIONS AND ALSO BETWEEN THE AIR-FUEL RATIO AND THE WEIGHT OF AIR PER SECOND

tendency on the part of the driver to maintain a fairly uniform speed, opening the throttle on grades and on poor roads, and vice versa, it is apparently worth while to derive the relations of any variation in the quality of the mixture for different loads, or throttle positions, corresponding to different constant speeds. The method used in such determinations is given below. Fig. 14 is a typical curve, on which are plotted both manifold depressions and qualities against the weights of air per second for full open, two-thirds and one-third throttle.

[47] Contributed by S. W. Sparrow, M. S. A. E.—Mechanical engineer, Bureau of Standards, Washington.

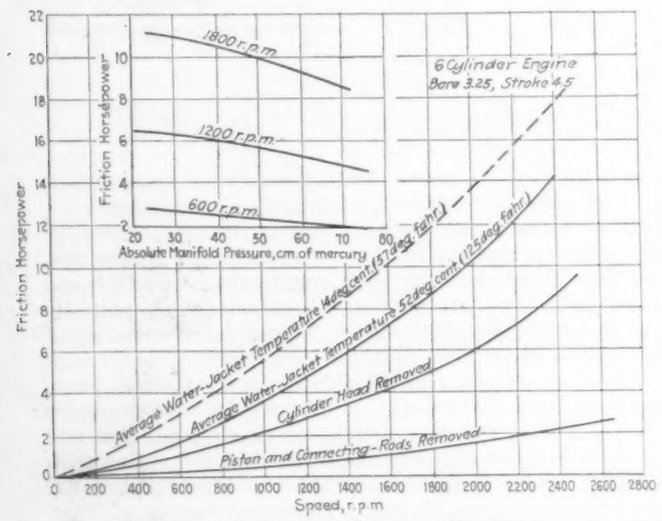

FIG. 15—RELATION BETWEEN THE FRICTION HORSEPOWER AND THE SPEED

The air-flow for open throttle with a manifold depression of 4 cm. (0.1575 in.) of mercury is arbitrarily taken as that corresponding to full engine-speed with full throttle. The air-flow for three-fourths and one-half full-speed with full throttle, are taken as three-fourths and one-half the weight at full speed, corrected slightly for the difference in manifold depression.

The air-flow for other throttle positions than full, corresponding to each of these speeds, is determined thus: If the volumetric efficiency is assumed to be constant, the volume of air used, measured beyond the throttle, at manifold pressure, remains constant for constant speed. If volumes and temperatures are constant, weights vary directly as the absolute pressures. Hence the weights of air used at different throttle-positions for constant speeds will vary as the absolute manifold pressure.

On the above-mentioned plots lines have been drawn giving the variation of weight with absolute manifold-pressure, 76-cm. (3-in.) manifold depression. Any point on one of these lines corresponds to a constant volume of air per second, or to a constant piston speed. Intersections of these lines with the weight lines for different throttle-positions gives the weights used for the given speed and the throttle position. Referring to the corresponding quality curve determines the mixture ratio.

The lower portion of Figs. 8 to 13 inclusive show the varying mixtures obtained with different throttle-positions for the carbureters tested, at full speed as arbitrarily determined three-fourths and one-half speed. It may be mentioned that the volumetric efficiency is not exactly constant as assumed in the above work, but varies with both the manifold depression and the engine speed. Such errors as are introduced by this approximation, however, are not important. In studying these curves, attention should be focused, not on the actual mixture proportions which depend largely on the adjustment of the carbureter, but on the change in the mixture proportions that result from a change in the load. Any departure from the proportions that give the maximum efficiency at a given load, results in a waste of fuel.

APPENDIX 3

THE MECHANICAL EFFICIENCY OF ENGINES WITH PARTICULAR REFERENCE TO PART-LOAD CONDITIONS[47]

The mechanical efficiency of the engine is the ratio of the power delivered at the clutch to that developed in the cylinders. The difference between these two powers is used to overcome the internal friction of the engine, drive the auxiliaries and draw in and exhaust the charge. All of this power loss is included in the term "friction horsepower," although some of the elements are not due, strictly speaking, to friction. Thanks to the wide-spread use of the electric dynamometer, the determination of this friction horsepower is comparatively easy. It consists in measuring the power required to drive the engine without fuel or ignition, while keeping all conditions as nearly as possible the same as when the engine is operating under its own power.

Fig. 15 makes clear the need for maintaining the jacket-water temperature at its normal value during such determinations. At 1000 r.p.m. the friction with a jacket-water temperature of 14 deg. cent. (57 deg. fahr.) is more than 50 per cent greater than when the temperature is 52 deg. cent. (126 deg. fahr.). This difference is a consequence of the higher viscosity of the oil at the lower temperature. One should not infer from these curves that the proper viscosity for an oil is that which

gives the minimum friction. On the contrary, the viscosity must be high enough to prevent metal-to-metal contact, even when the oil is diluted with fuel. Nevertheless, the curves do illustrate the excessive friction-loss that will ensue from use of oil of a viscosity unnecessarily high.

A rough comparison of the magnitude of the several elements that comprise the friction loss is given by the lower three full-line curves. Similar comparisons have been made by Mr. Ricardo and by the engineering division of the Air Service at McCook Field.[48] All results show piston friction to be responsible for a large proportion of the total loss. At 2400 r.p.m., with the cylinder-head removed, the power required to drive the pistons and the connecting-rods is three times as great as that to operate all the rest of the engine.

It is frequently assumed that the difference between the friction horsepower measured under normal conditions and that obtained with the valves or cylinder-head removed represents the pumping loss. Values of the pumping loss obtained in this manner are considerably higher than those given by actual indicator-card measurements. It appears, therefore, that the removal of the cylinder-head not only eliminates the pumping loss but also reduces the piston friction through the change in pressures that results. This statement is made reluctantly because it has been found that the friction of the engine under power is not sensibly different from that when the engine is driven by the dynamometer, in spite of the lower pressures in the latter instance. At present the best that can be said is that measuring the pumping loss by this method of difference is open to question.

It is well known that the mechanical efficiency of the automobile engine decreases with a decrease in the load. One cause is the increase in the friction horsepower that results from closing the throttle. Fig. 15 shows this effect at three speeds, the absolute manifold pressures indicating the amount of throttle opening. That this is not the major cause of the low efficiency will be evident from Fig. 16. Here the mechanical efficiency and fuel consumption are plotted against the brake horsepower. The fuel-consumption calculations are based upon 0.55 lb. of fuel per i.hp-hr., a value that is assumed to be constant over this load range. The dash-line curves show results that might be obtained if the friction horsepower did not increase with the closing of the throttle. At 20-per cent load the upper curve shows a 20-per cent increase in the efficiency to be possible; that is to say, a car now going 15 miles on a gallon of fuel could then go 18. Even under these conditions, at 20-per cent load the specific fuel-consumption would be 40 per cent greater than at full load. The low efficiency of the automobile engine is thus seen to be due primarily to the fact that it normally operates at a small percentage of its maximum power. This reserve power, however, if not actually a necessity is at least a luxury that will not be willingly relinquished.

In conclusion, emphasis may well be placed on the importance of keeping the friction as low as possible because its influence is multiplied at reduced throttle. For example, under the conditions of Fig. 16, an increase of 1 friction hp. would increase the fuel-consumption at full load only 3 per cent but at 20-per cent load, 9 per cent. Small gains in mechanical efficiency thus justify the expenditure of considerable effort toward their attainment.

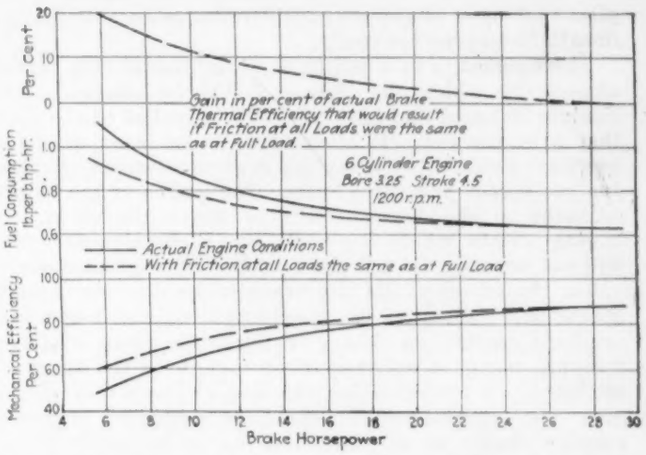
Per Cent
Gain in per cent of actual Brake Thermal Efficiency that would result if Friction at all Loads were the same as at Full Load.
6 Cylinder Engine
Bore 3.25 Stroke 4.5
1200 r.p.m.
Fuel Consumption lb. per b.hp.-hr.
Actual Engine Conditions
With Friction at all Loads the same as at Full Load
Mechanical Efficiency Per Cent
Brake Horsepower

FIG. 16—RESULTS OF TESTS ON A SIX-CYLINDER ENGINE SHOWING THE RELATION BETWEEN THE MECHANICAL EFFICIENCY, THE FUEL CONSUMPTION AND THE BRAKE HORSEPOWER

APPENDIX 4

IGNITION TIMING[49]

The point in the cycle at which the ignition spark should occur in order that the engine efficiency may be a maximum is affected both by the speed of the engine and by its load. Many systems are constructed so that the timing of ignition changes with any change in the speed. There have been, in experimental use at least, devices which enabled the ignition timing to be controlled by the manifold pressure in an endeavor to meet the requirements of changing load. That the spark control-lever still appears on the steering-wheel of most cars, however, im-

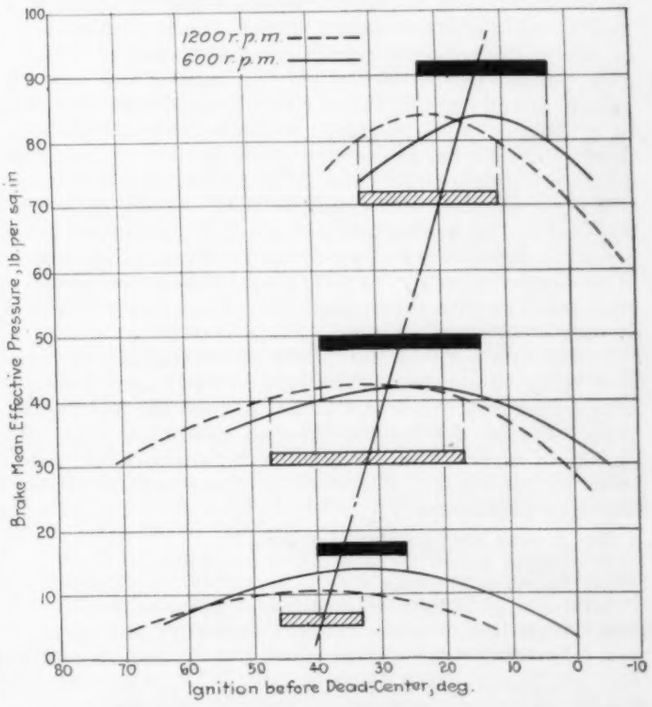

FIG. 17—INFLUENCE OF IGNITION TIMING UPON THE BRAKE MEAN EFFECTIVE PRESSURE

[48] See High-Speed Internal-Combustion Engines by H. R. Ricardo, published in THE JOURNAL, October, 1919, p. 317, and Experimental Separation of Engine Losses, published in *Automotive Industries*, June 10, 1920, p. 1338.

[49] Contributed by S. W. Sparrow, M. S. A. E.—Mechanical engineer, Bureau of Standards, Washington.

plies that most engineers consider the automatic devices unsatisfactory or too costly.

There seems to be a dearth of experimental data on the amount by which the timing should be changed with changes in speed and load. Fig. 17 is typical of the data that are required. It shows the brake mean effective pressure obtained with various degrees of spark-advance for two speeds and three loads. The length of the blocks adjacent to the curves indicates the range of spark-timing within which the brake mean effective pressure will not be more than 5 per cent less than its maximum value. Inasmuch as the fuel consumption does not change appreciably so long as the speed and the throttle opening are kept constant, a change in the brake mean effective pressure means a corresponding change in the thermal efficiency. A compensation for load changes that would give the spark-advance brake-mean-effective-pressure relation shown by the dash line would be fairly satisfactory for the two speeds tested. Data of this sort should be obtained over the range of speeds and loads at which the engine will operate in service.

It is a common belief among automobile drivers that the maximum efficiency is obtained with the maximum advance at which the engine will operate without knocking. Under the conditions shown by the lower curves no knock was obtained even with the maximum advance so that an adjustment in accord with the aforementioned belief would result in a *decrease* in efficiency of over 50 per cent. With manual control of spark-timing the possible advance should be limited to prevent this excessive loss of efficiency.

APPENDIX 5

Fuel Knock[80]

The phenomenon variously known as fuel knock, detonation and pinking has assumed so much importance because of the practical limitations it imposes on compression-ratio and consequently on fuel-economy that there has come to be much discussion and more speculation as to the exact nature of what takes place in an engine cylinder when this phenomenon occurs. However, neither the discussion nor the mass of information gained directly and indirectly from experiments has led to a definite understanding or even to a satisfactory theory of the nature of the phenomenon. The term detonation implies that something occurs in the cylinder which corresponds to the detonation of a high explosive. Such conditions are easily produced in explosive gas mixtures but there is scant proof that the same thing occurs in an engine cylinder. In fact, some of the experimenters most familiar with these phenomena doubt the possibility of such occurrence.

To clear up some of the indefiniteness, an attempt has been made to enumerate the various facts and observations concerning fuel knock and to discuss the bearing of these facts on the several theories that have been advanced to explain the nature of the phenomenon. Fuel knock as ordinarily understood is characterized by the following phenomena:

(1) A very sharp metallic noise
(2) Bright yellow flame within the cylinder
(3) Decrease in power
(4) Increase in heat rejected to the jacket-water
(5) High instantaneous cylinder pressure
(6) Destructive mechanical effects
(7) Occurrence of smoke in the exhaust
(8) Preignition, in most cases

Observations show that the occurrence and intensity of the knock are intimately related to the following factors:

(1) Chemical composition of the fuel
(2) Ignition timing
(3) Compression-pressures
(4) Mixture-ratio
(5) Position and number of spark-plugs
(6) Shape of cylinder and piston-head
(7) Temperature of the charge
(8) Cylinder temperatures

Aside from more or less random speculations, there are at least three rather definite theories or hypotheses presented as explanations of the character of this knock phenomenon. These are (*a*) what may be termed the mechanical-knock theory, which explains the sound by means of some mechanical knock or impact between parts of the engine mechanism, as for instance between cylinder wall and piston, or between shaft and bearings. This theory does not attempt to explain the cause of pressures which must exist to produce these mechanical impacts. On this theory it would be assumed that there is no necessary difference between the so-called fuel knock and any other purely mechanical knock, except that the former is primarily due to cylinder pressures, while the latter may be due to inertia effects, etc.

Another theory (*b*) is that proposed by Ricardo, which explains the sound and other phenomena as due to a sudden very rapid increase in cylinder pressures. It is assumed that a portion of the charge, compressed to the ignition point by the expansion of the portion first ignited, burns simultaneously, causing a very sudden rise in pressure. This theory does not contradict the former, but assumes that the sound may be produced either by the sudden distortion of the cylinder walls by gas pressure, or by mechanical impacts in the mechanism, due to the sudden pressure-increase. It seems to require the assumption that a fuel will show a tendency to knock somewhat proportional to its spontaneous-ignition temperature but it makes no attempt to explain the nature of the explosion or detonation which occurs in the compressed charge.

A third theory (*c*), which may not necessarily contradict either of the foregoing, is the so-called detonation-wave theory. According to this the process of explosion is explained somewhat as follows: When ignited the wave of combustion spreads out from the ignition point at a relatively slow but increasing rate. Under certain conditions before the flame has filled the combustion space, its rate of motion increases to what is known as *detonation* velocity, a velocity so high as to constitute practically the *simultaneous* burning assumed by Ricardo. An interesting theory regarding the nature of the chemical reactions which account for the increase in flame velocity has been proposed by Midgley.[81] Such detonation waves in gas mixtures were first discovered in 1881, independently by Berthelot and by Mallard and Le Chatelier. These velocities and characteristics are reasonably well understood. The velocities are from 1 to 2 miles per sec., sufficient to account for the sound and pressure effects which are observed in engine cylinders. But in direct experiments it seems never to have been possible to attain these velocities within the short space in an engine cylinder.

Of the three theories, the first does not attempt an

[80] Contributed by H. C. Dickinson, M. S. A. E.—Physicist in charge of power plants research, Bureau of Standards, Washington.

[81] See Combustion of Fuels in Internal-Combustion Engines by Thomas Midgley, published in The Journal, December, 1920, p. 489.

explanation of the phenomenon. Whatever causes the characteristic sound is certainly actuated by the sudden increases in cylinder pressure which have been measured repeatedly. The direct causes of these increases in pressure are of more interest than the source of sound and the only attempt at explanation of sudden pressure-increases is found in the theories (*b*) and (*c*); hence, these appear of greater interest. In considering the bearing of known and observed facts on these theories, it is important to note that the one important difference between the two theories is that (*b*) assumes that the cylinder pressures are true pressures produced by a sudden increase of pressure throughout the cylinder, while (*c*) includes the assumption that the high pressure may be localized impacts of the detonation wave. This means that the maximum pressure may not be by any means the same at different points within the combustion space.

The short metallic sound produced by fuel knock, particularly in light-weight cylinders, suggests the impact of a very light hammer on a heavy anvil. Observations of the velocities imparted to a light steel rod resting on the top of a Liberty engine cylinder during detonation show a number of interesting facts. For instance, it is found that under detonation conditions this cylinder-head is distorted with a velocity which might correspond to that of a tuning-fork, corresponding to that of a sound having a pitch above the range of the piano keyboard, or of the order of 4000 vibrations per sec. The action of the cylinder pressure is therefore entirely sufficient to account for the characteristic sound produced.

The characteristic bright yellow flame within the cylinder, which is observed to accompany the fuel knock, has been shown by stroboscopic observations to be of very short duration, occupying not over 10 deg. rotation of the crankshaft or about 0.001 of a sec. in time. Evidently the flame phenomenon is worthy of more careful study as to its exact time of occurrence, its duration and the characteristics of the intermediate products of combustion. Such information might go far to explain the knock phenomena.

A decrease in the power output accompanies knock but there seems to be no very close relationship between power and knock. For instance, the curves in Fig. 18 show the power output and maximum cylinder-pressure with reference to ignition timing. Throughout the range of peak pressures noted on the plot, fuel knock was present and at the highest pressures was violent; yet there is no marked irregularity in the horsepower curve. Apparently fuel knock of itself does not reduce the power but rather the conditions at which the knock occurs are not those for maximum power. Whether these conditions would produce the maximum power with a fuel that did not knock cannot be answered with certainty.

It has been observed that whenever fuel knock develops due to a change in the timing or pressure, or a change in the fuel, there is an abrupt increase in the heat rejected to the jacket-water. There are several possible explanations of this: (*a*) the increase in temperature and pressure may directly increase jacket losses by increasing radiation and connection to the cylinder walls; (*b*) the increase in pressure may increase leakage past the piston; (*c*) high-velocity detonation-waves, if they exist, may transmit energy to the walls by impact and (*d*) the burning of oil directly on the cylinder walls, due to high temperature of the charge, may add to the heat loss.

Whatever the immediate cause of this increase of heat loss, the fact is significant. According to either of the

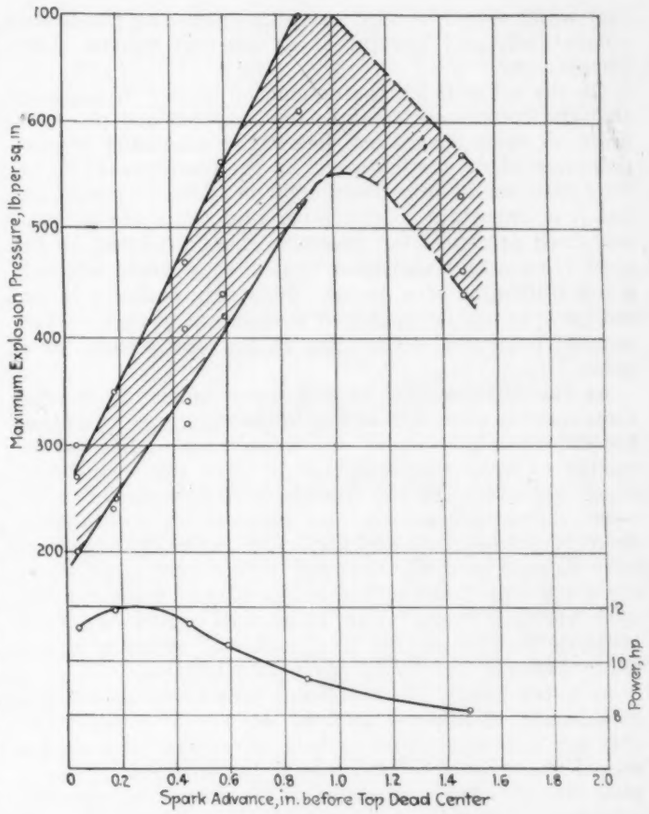

FIG. 18—CURVES SHOWING THE RELATION BETWEEN THE SPARK TIMING, THE MAXIMUM PRESSURES REACHED IN THE CYLINDER AND THE POWER DEVELOPED

two proposed theories, assuming localization and burning of a portion of the charge under increased pressure, it might be expected that the excess heating effect would be most pronounced at the particular location where this local combustion took place. Experiments to verify this by thermoelectric couples inserted in the cylinder in various positions with relation to the firing plug, show no significant difference in the temperature-rise for different locations. These observations seem to show that the excess heating effect during knock is *not* localized as might be expected. The effects of increased radiation and of combustion of oil would be in accord with these observations.

Extremely high cylinder-pressures have been found by different observers by various indicating devices. In one case with a compression-ratio of about 5 to 1 pressures of 1300 lb. per sq. in. were observed to occur consistently at each explosion; this pressure being the maximum measurable with the apparatus at hand. It is safe to assume that the maximum pressures were at least 1500 lb. and probably much higher. These pressures occurred with kerosene as fuel.

The amount and distribution of these pressures is of importance in relation to the two theories advanced. According to the Ricardo theory, the pressure may be uniformly distributed throughout the combustion-chamber, although this is not a necessary assumption. If uniformly distributed, the pressure must not exceed that which could be produced by burning all the fuel at constant volume at intake pressure and then compressing adiabatically to the final volume. In fact, due to the nature of the process, the pressure can hardly exceed

that which would be produced by compressing the charge adiabatically and burning it at constant volume under compression.

On the other hand, the detonation theory presupposes that the maximum pressures are localized and places no limit on their magnitude below the calculated impact-pressures of detonation-waves in the compressed charge. This limit would be between 5000 and 7000 lb. per sq. in., but it is important to remember that these are not true sustained pressures but resemble those produced by the blast from a high explosive, that is they would last only a few millionths of a second. It is very doubtful if any indicator in use is capable of responding to such instantaneous pressures, other than to register a kick, so to speak.

As for experimental results, some indicator observations seem to show differences in the maximum pressures for different locations of the firing plug; other results worthy of equal confidence fail to show any such differences whatever. At the Bureau of Standards the maximum indicator-pressure, the increase in combustion-chamber temperature and distortion of the cylinder-head have all been carefully analyzed for different locations of the firing plug to detect any localization of pressures and none has been found. This appears to constitute strong evidence that no marked localization of pressure occurs which depends directly on spark-plug location.

As noted above, the maximum pressures reached are occasionally as high as 1500 lb. per sq. in. at least. If they are normal uniform cylinder-pressures, they cannot exceed the pressures that would be produced by complete simultaneous combustion of the charge before compression, as stated. Moreover, from an examination of the pressure-change it is evident that comparatively little of the charge is burned much before dead-center; therefore, in practice, the knock pressures cannot exceed maximum computed pressures unless they are due to some effect other than normal combustion of the charge. Maximum pressure produced by the latter cause can be determined approximately. The maximum temperature reached on compression in the ratio 5 to 1 and combustion of a normal charge, taking account of dissociation, is given by Pye in *The Automobile Engineer*[*] as from 2500 to 2700 deg. cent. (4532 to 4862 deg. fahr.). If dissociation is neglected, the temperatures are computed as about 3000 deg. cent. (5432 deg. fahr.). As the effect of dissociation is to lower the temperature, with a slight increase in volume relative to temperature, take the higher figure. This temperature corresponds to, roughly, 3250 deg. cent. (5882 deg. fahr.) absolute. If, therefore, the pressure were 1 atmosphere before compression and 5 atmospheres after compression and the temperature 300 deg. cent. (572 deg. fahr.) absolute before compression, the pressure after compression and combustion has a maximum value of $5 \times 3250 \div 300$, or slightly over 50 atmospheres, which is about 750 or, say, 800 lb. According to Pye's results the temperature would be only about 500 deg. cent. (932 deg. fahr.) higher and the pressure only about 1000 lb. per sq. in., if the combustion took place before compression. Pye gives 700 lb. per sq. in. as the maximum attainable cylinder pressure. This neglects the volume of water vapor which would increase the pressures somewhat.

Remembering that these are absolute *maximum* pressures if Pye's results are to be accepted, pressures of over 1000 lb. per sq. in. must be due to some cause other than normal gas combustion. In other words, such pressures *cannot* occur *simultaneously* at all parts of the cylinder.

Destructive mechanical effects are somewhat difficult to interpret. Broken spark-plug porcelains, cracked piston-heads and burned-out bearings, as well as general evidence of excessive mechanical stresses, accompany continued detonation, particularly in aircraft engines. But none of these effects is subject to direct measurement. An index of the nature of the pressure-rises which accompany knock is had, as referred to above, by observing the height to which a light weight is projected from its seat on the cylinder-head. A measurement of this height and of the deflection of the cylinder-head per unit pressure-change leads to the following conclusions, which can be readily computed from the following data:

(1) The maximum height is 1½ in. The deflection of the cylinder head at this point is 0.0005 in. for each 100 lb. per sq. in. rise of pressure
(2) The rate of pressure-increase required to produce this effect is, roughly, 7,000,000 lb. per sq. in. per sec.
(3) The pressure was found to rise about 550 lb. per sq. in. above normal maximum when detonation took place, and to produce this rise at the above rate would require less than 0.0001 sec.
(4) For the Liberty engine cylinder, the combustion flame must traverse the explosive mixture at a rate of *at least* 4500 ft. per sec. to produce this observed rise of pressure. It is of interest to note that this figure is in fair agreement with the detonation velocities found by Dixon for explosions in tubes

The observed occurrence of black smoke in the exhaust may have many explanations. One of the most obvious, that it indicates incomplete combustion, is apparently contradicted by the observed fact that the *indicated power*, therefore the amount of energy liberated in combustion is at least as great with as without fuel knock. I know of no definite conclusions which can be drawn from this occurrence.

The frequent occurrence of preignition following violent fuel knock is a natural sequence of the increased amount of heat rejected to the jackets, spark-plugs, valves, etc. It hardly needs any other interpretation.

With reference to the several factors which affect fuel knock, the general consideration that the phenomenon is intimately connected with the process of combustion would indicate that any change in conditions would affect fuel knock.

The very marked effect of the chemical composition of the fuel and particularly of the addition of certain anti-knock compounds as demonstrated by Mr. Midgley and others shows the extreme sensitiveness of the phenomenon. In this connection, it should be noted that the comparison of different fuels by these observers has shown that some fuels which readily ignite spontaneously do not knock and vice versa. This seems to be strong evidence contrary to the spontaneous-ignition theory of Ricardo.

The effect of ignition timing has been shown by observations at the Bureau of Standards to be of very much more significance than previously supposed. For instance, it is proved that knock can be made to appear on cutting out one of two spark-plugs, or under other conditions to appear when the second plug is switched in; and these effects are apparently due solely to the changes in the effective timing of the combustion relative to piston po-

[*] See Character of Various Fuels for Internal-Combustion Engines by H. T. Tizard and D. R. Pye, published in *The Automobile Engineer*, February, 1921, p. 55.

sition. The use of two plugs in effect advances the timing. It is shown also that knock can be prevented much more readily and with less loss of power by careful regulation of ignition timing than had been supposed. However, it is difficult to draw any conclusions from these facts as to the nature of the fuel knock.

The other factors enumerated, such as the compression-pressure, mixture-ratio, temperature of the charge, and temperature of the cylinder, seem to offer no direct evidence as to the probable validity of the two theories under consideration. They might, however, afford valuable data if the nature of knock were better understood.

The number of ignition points and their relation to the shape of the combustion space seem to be of significance. It appears to be a fact that the larger the number of ignition points, and the nearer these are to all portions of the charge, the less is the tendency to fuel knock. The much discussed subject of turbulence appears to be probably of significance mainly as it affects the distribution of the burning mixture. Distribution of burning charge should be nearly equivalent to distribution of ignition points. Obviously the maximum rate of pressure-increase which can be produced by normal burning, occurs with the greatest amount of flame area, but the larger the number of spark-plugs the greater the total area of flame, at least at the beginning of the combustion; yet this maximum area never produces sudden pressure-rises of the order observed. Something beside normal rates of burning are, therefore, necessarily involved.

The conclusions to be drawn are as follows:

(1) The two theories of fuel knock, that of Ricardo and the detonation wave theory, do not appear to be essentially contradictory but make somewhat different assumptions as to the maximum pressure

(2) The sound produced by fuel knock can be adequately accounted for by the distortion of parts of the cylinder, without assuming any metallic impacts

(3) The excess heating-effect accompanying detonation does not appear to be localized in any particular portion of the cylinder, as might be expected from either theory

(4) No differences in maximum pressure when measured in different positions relative to the point of ignition have been definitely demonstrated, although some observations indicate them

(5) The maximum pressures measured seem to exceed those which could be produced by the normal explosion of the charge. This indicates that some phenomenon such as detonation must be assumed to account for the pressures observed

(6) The rates of increase of pressure which have been observed are such as to require the existence of some such disturbance as detonation, as an adequate explanation

(7) It has been shown that fuels which are particularly subject to auto-ignition by compression are not necessarily subject to fuel knock. This indicates that the spontaneous ignition theory of Ricardo, in its simplest form, is at least incomplete

From the foregoing, it may be concluded that whatever the phenomenon of fuel knock may involve, the observed facts are in reasonably close agreement with the theory that the high pressures and attendant phenomena are the result of an abnormal type of combustion which can be accounted for with a reasonable degree of completeness by the so-called detonation theory. The only serious discrepancy between this theory and the observed facts appears to be the failure to discover positions within the cylinder where maximum pressures and temperatures occur. If it can be assumed that the impact waves, which are taken as an explanation for the very high pressures, are capable of reflection within the combustion chamber, the hypothesis of localized maximum pressures is not essential to the theory.

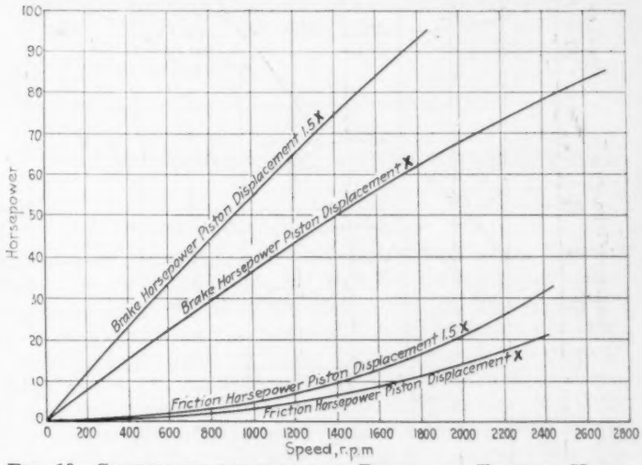

FIG. 19—COMPARISON BETWEEN THE BRAKE AND FRICTION HORSEPOWER OF A FOUR AND A SIX-CYLINDER ENGINE AT FULL THROTTLE

APPENDIX 6

RELATIVE MERITS OF LARGE SLOW-SPEED AND SMALL HIGH-SPEED ENGINES[53]

For comparison one engine is assumed to have a piston displacement 50 per cent greater than that of the other. Rear-axle ratios are taken as 3 and 4.5 for the large and the small engine, respectively, in order that substantially

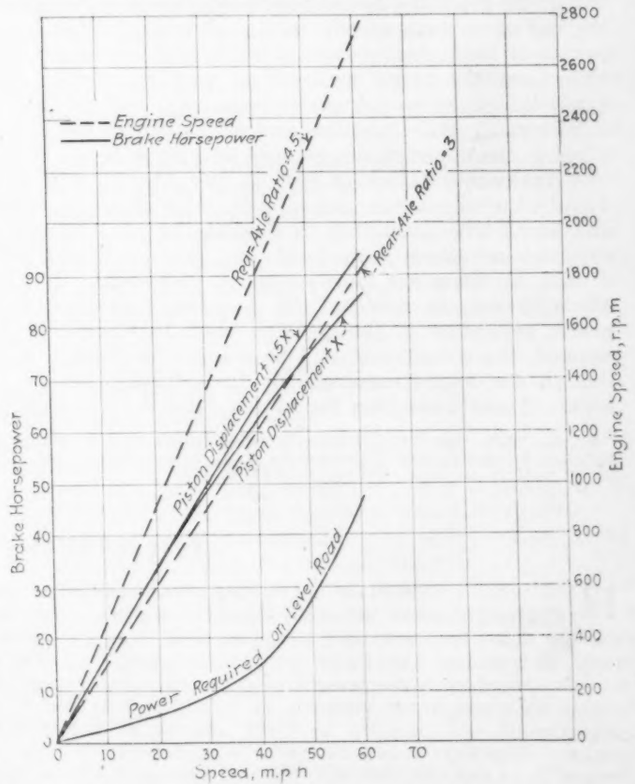

FIG. 20—BRAKE HORSEPOWER REQUIRED TO PROPEL A CAR AT VARIOUS SPEEDS ON A LEVEL ROAD

[53] Contributed by S. W. Sparrow, M. S. A. E.—Mechanical engineer, Bureau of Standards, Washington.

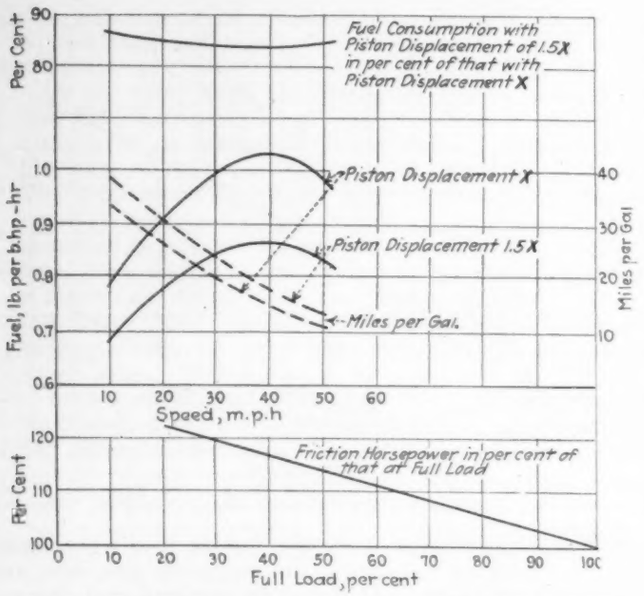
Per Cent
Fuel Consumption with Piston Displacement of 1.5X in per cent of that with Piston Displacement X
Piston Displacement X
Piston Displacement 1.5X
Miles per Gal.
Fuel, lb. per b.hp.-hr
Miles per Gal
Speed, m.p.h
Friction Horsepower in per cent of that at Full Load
Per Cent
Full Load, per cent

FIG. 21—THE RELATION BETWEEN FUEL CONSUMPTION AND THE FRICTION HORSEPOWER AT FULL AND PART LOADS

the same torque can be delivered to the rear wheels in each case. Fig. 19 shows brake and friction horsepowers for the two engines at full throttle. The data for the small engine were obtained from test and from these same figures the values for the large engine were predicted. Rather than inject a detailed analysis of the relation of friction losses to piston displacement, it is assumed that the increase in displacement is obtained by adding two cylinders to a four-cylinder engine and that the friction power is increased 50 per cent thereby.

Fig. 20 gives the brake horsepower required to propel the car at various speeds on a level road.[84]. The upper curves of brake horsepower give full-throttle results and thus show the power available at each car-speed. The grade that the car will negotiate and the car's ability to accelerate depend upon the amount by which the power given in the upper curves exceeds that given in the lower.

A fuel consumption of 0.55 lb. per i.hp-hr. has been used in the calculations for all conditions of engine speed and load. The possibility or desirability of obtaining a constant indicated thermal efficiency under all such conditions is discussed more properly elsewhere. If this efficiency remain constant for a given development of power, regardless of the speed at which that power is developed, the comparison will be essentially correct, even though the figure assumed for fuel-consumption be in error. Tests made thus far at the Bureau of Standards indicate that the efficiency for a given load is independent of the speed over the range of speeds covered in this discussion. One further assumption, the relation of friction horsepower at part load to that at full load, must precede the calculation of fuel-consumption per brake horsepower-hour. An approximate relation, derived from tests on an automobile engine and given in Fig. 21, has been used for this purpose.

In calculating the fuel-consumption in pounds per brake horsepower-hour, the first step is the determination from Fig. 20 of the brake horsepower developed at the speed selected. The same sheet gives the brake horsepower developed at full load at that speed and hence permits the percentage of full load at which the engine is operating to be deduced. Knowing this, the friction horsepower can be obtained by the relationship between the friction horsepower at full and part load, given in Fig. 21, the friction horsepower at full load being given in Fig. 19. Three steps remain: (*a*) the addition of the friction horsepower to the brake horsepower to obtain the indicated horsepower; (*b*) the division of the brake horsepower by the indicated horsepower to obtain the mechanical efficiency; (*c*) the multiplication of the fuel-consumption expressed in pounds per indicated horsepower hour (0.55) by the mechanical efficiency, to obtain values of fuel-consumption in pounds per brake horsepower-hour. Results calculated by this method are given in Fig. 21.

Percentage values, given in Fig. 21, show the larger engine to have a 15 per cent lower fuel-consumption than the smaller engine. This figure is unfair to the small engine, as the increased weight of the large engine means that the ability of the car is reduced. Published data show that usually in a series of engines built by any one company, the weight per brake horsepower is less the greater the horsepower. Let this effect be neglected to take care of any weight increase in the transmission and drive required by the larger engine and let the increase in the engine weight be 50 per cent. As the engine-weight is about 15 per cent of the car-weight, the weight of the latter will be increased 7.5 per cent. It is concluded, therefore, that the car has lost 7.5 per cent in ability and gained 15 per cent in economy. Furthermore, it is evident that increasing the large engine until its ability equals that of the small engine will still leave it somewhat superior from the standpoint of economy.

The foregoing analysis does not prove the superiority of either type of engine for every case. Engine cost, durability, relative ability for slow-speed operation, and many other factors must influence such a decision. There is a widespread belief that the small high-speed engine is vastly more efficient than the larger slow-speed type. The purpose of this discussion is to challenge that belief and to show the factors of major importance in the comparison of the two types.

[84] These data are taken from a paper entitled Fuel Problem in Relation to Engineering Viewpoint by A. L. Nelson which was published in THE JOURNAL, February, 1921, p. 101.

HIGHWAY TRANSPORT

HIGHWAY transport is not a single responsibility. Its efficiency depends not solely upon the highway engineer nor the automotive engineer but upon their hearty cooperation. It is just as harmful to limit the axle weight of trucks by laws based upon the present condition of roads, except of course as a temporary measure, as to expect that highway departments will respond to every caprice of automobile design. Highways must, however, be considered as only a means to an end and that end, national transport. It is just as necessary to pass regulations governing the nature and the strength of roads as to pass regulations controlling the weight and speed of the vehicles using them. The future highway must be constructed with regard to its use by self-propelled vehicles, and the automotive engineer, because of the heterogeneous types of road surfacing, must design and construct reasonably light vehicles capable of carrying its required load at minimum cost. Until that cooperation has produced the desired results a very rigid enforcement of the maximum-load regulation is an absolute necessity.—*Engineering News-Record.*

Air Transportation and the Business Man

By V. E. Clark[1]

Semi-Annual Meeting Paper

IT is more than 12 years since the first successful heavier-than-air craft flights were brought to the attention of the public. Generally speaking, we have not been immediately concerned in the business world with the advent of the new era in commercial progress ushered in by those first flights, and we believe we have gotten along well without the aid of aircraft, thus far. Yet, if a person wishes to travel or to send a letter from Chicago to San Francisco, he might use a prairie schooner or a Pony Express but he does not; if he wishes information from an office eight blocks distant he might walk there but he does not because it never occurs to that person to do a thing in any other than the quickest way. Probably they do not present the cheapest ways, directly, of transportation or communication, but the railroad, the telephone, the telegraph, the cable, the motor car and the motor truck, are necessities; progress, competition and habit have brought us to a stage such that we could not "live" without them because things would move too slowly.

As a fundamental fact, proved by history, can we not state that any vehicle or device that permits a material saving in time of transportation or communication between two points does in effect annihilate space and is therefore certain of becoming a necessity to the civilized world? Although the railroad and the motor car cannot be displaced, any thinking person knows that it will be impossible to prevent aircraft from taking a serious part in the activities of the commercial world; but it must be admitted that no air-transportation service has as yet been successful from the standpoint of returns on the investment. Many persons interested in aeronautics may wonder why and become discouraged, forgetting that the airplane is only 12 years old and that railroads and motor cars were, at the same stage of development, by no means valuable as money-makers.

I will attempt to answer the question as to what must be done before air transportation will become a serious factor in the transaction of business; endeavoring to give an honest exposition of the conditions which those interested in commercial aeronautics must meet. The thought is that most of the publicity given to civil aviation has been written by fanatics or by those who have had something to sell. Their published articles have, unfortunately, been so highly colored and often so impractical that the logical reaction on the conservative business man has been a deep-rooted suspicion of anything he sees in print on the subject. It is hoped that the treatment of the subject which follows may assist in balancing the scale of public opinion, and in clarifying and guiding the expectations and efforts of those who are associated in the development of the aircraft industry. It may in a measure serve to curb the unrestricted enthusiast, encourage the disheartened aviation devotee and arouse at least a tolerant interest among progressive business men. In the first part a few of the suggested uses of aircraft in the transaction of business are considered; the second part sets forth some of the present obstacles to the development of aircraft transportation and suggests means toward surmounting them. My hope is that discussion originated by those who may be interested will lead to constructive thought looking toward a solution of the problem.

Suggested Business Uses for Aircraft

Airships and airplanes are vehicles having such attributes as to place them in a unique class, as compared with other means of transportation. An airplane can carry a material thing from one point to another in a much shorter period of time than is required by any other known vehicle. It is inherently more speedy, and it can pursue a straight-line or a great-circle course which is the shortest distance between two points. Neither land nor water, nor mountain nor canyon, can interfere. Travel by motor car and truck is often impeded by bad roads. Aircraft do not require, for operation, the construction and maintenance of roads or railroads. In this respect, aircraft travel is comparable with travel by seacraft, except as to speed. Seacraft, however, cannot take the straight-line course between two points if land intervenes. All points cannot be connected by straight lines, and steam or electric trains must always lose time while dodging mountains and bodies of water. Delays at connecting points are unavoidable and schedules cannot be elastic because collisions would result; but the schedules for aircraft can be changed as exigency demands, without danger of collision. Sometimes the telegraph and the telephone expedite communication; but all of the world's business cannot be transacted in this way. If business did not require personal contact, we would not continue to crowd the passenger, the mail and the express trains. By using aircraft we can provide a platform, a "magic carpet," susceptible of being moved quickly to any point over the earth, and from which the country and the objects on the ground below can be seen, mapped or photographed, more completely and accurately than in any other way. Mindful, then, of these distinctive inherent attributes, let us recount some of the suggestions that have been made for using aircraft to aid and expedite the world's business, considering first the possibilities in the transportation of important confidential business or personal communications.

One can safely promise that before many years an airplane will fly from Chicago to New York in less than 3 hr. Even with mechanical development as it is today, this is possible.[2] We know that mail has been delivered in New York 33 hr. after it left San Francisco, constituting a saving of 3 days. To accomplish this, one pilot flew practically all night. It appears logical to assume

[1] M.S.A.E.—Chief engineer, Dayton-Wright Co., Dayton, Ohio.

[2] See Maintaining Airplane Engine Power at Great Altitudes, published in The Journal, April, 1920, p. 245.

that the real saving in time, to the business man, will be accomplished by night flights. Consider an hypothetical case of a business firm in Chicago which is suddenly confronted on Wednesday afternoon with a problem of vital importance, the solution of which depends upon information from a New York firm with which it has business connections. Perhaps the officials dare not use the telephone or telegraph, not only on account of the nature of the messages back and forth being too confidential but because complicated tables of data with accurate drawings must be transmitted both ways. Or, perhaps it becomes necessary to pass an important measure affecting the policy of the company and it is imperative that a trusted official go to New York for direct personal conference. To accomplish the desired result, which may involve millions of dollars or the defeat of a competing company, the answer must be returned from New York by Friday morning. Train mail would get the answer back possibly by Monday morning, or 3 days too late; but an airplane, navigating at night and operating on a regular schedule, could carry the complete query or the official, with data and drawings, to New York during Wednesday night, allow 16 hr. Thursday for the New York firm to work on the problem, and deliver the answer in Chicago early Friday morning. Another hypothetical case is that of a man drawing a $10,000 salary who is called upon to make a trip in the interest of his company to a point distant 200 miles in an air-line. The round trip by day train would require say 20 hr. and cost $25. The round-trip by five-passenger airplane today would require 4 hr. travel time and cost say $80. The man's time being worth $5 per hr. to his company, it is evident that airplane travel would be the cheaper.

If it seems that this is far-fetched and that such instances do not occur often enough to warrant an elaborate airplane service, let us remember that before the public became accustomed to the idea of the telephone or of the railroad it did not feel the need of them. Convenience and speed quickly cultivate habit. The banker and the broker are interested in knowing that one or two days' time can be saved each way every day between Chicago and New York, by night air-service, in the transporting and clearing checks, drafts, securities and certificates. Three days can be saved between the Atlantic and the Pacific coasts. Since so much time can be saved between points connected by train service as fast and as frequent as is humanly possible, consider what can be accomplished by aircraft in competition with boats or trains between points to which the route is circuitous or there are only one or two slow trains daily. Consider also the linking together of places which might otherwise be important except that they have no railroads. The man who is a director of corporations located in different cities and the man who has manufacturing interests in different towns will use the air as a medium for travel because they are eternally pressed for time. Such men can save say three-fourths of that part of their life previously spent in travel, or perhaps one-tenth of their whole life. Lord Cowdray has said, "The advent of the era of flight will lengthen our lives because it will enable us to do more in a given time than we have been able to do before." I quote also from Aerial Transport, by G. Holt Thomas:

> Regarding Commercial Transportation, the development of flying and of such an extraordinary power as that of the wireless telephone, may have influences which will be simply revolutionary, in the years to come, on the everyday life of the world. To be able to send the sound of our voices without the aid of wires over an increasingly wide radius of space; to travel through the air in all directions at a speed many times as great as that by land or sea; to rush at these great speeds with equal facility over land or water; and then to combine these two wondrous potentialities in a unified and perfect system that spreads its network over the whole of the globe, will give us powers which, when compared with our limitations today, will appear almost to render us superhuman. From the finite we shall seem to come almost to the infinite; time and distance, those limitations that are so irksome to the free flights of the human mind, will have lost very much of their hampering restriction. Men controlling vast industries, the captains who steer our great barks of commerce, will no longer feel that sense of irritation which comes from a constant struggle against imperfect communications. For we must remember that today, marvelous though the spread of science has become, we are still very much in the dark ages so far as international communication is concerned.
>
> Concerning the scope of the flying boat, the more one looks into this particular question the more impressed one is by its possibilities. Up some of the great rivers, for instance the Amazon, thousands of miles long, there is a teeming trade to be done, but it languishes simply owing to the slowness and difficulty of communication. Not only are there strong currents to be contended with, but the navigation of steamships often becomes a question of extreme caution owing to the presence of shifting shoals and other obstructions. Thus, stages of hundreds of miles must be traversed at a crawling pace; whereas, in a powerful flying-boat of modern type we have a craft capable of ascending into the air with an appreciable load and of following the course of these big rivers at an average touring speed of say 80 to 100 m.p.h., coming down to the surface of the water whenever a halt is deemed advisable and putting down or picking up passengers and goods just as is required. An organized flying-boat service operating on a regular time-table up these great rivers of the world would not only serve the existing trading communities on these rivers in a manner which is impossible at present but create and stimulate new trade in a way I think would be surprising, bringing indeed a new lease of life to these great water routes, and setting men to work along them with a new ambition and purpose.

The Dominion of Canada has more inland waterways than any country or province and it has very few railways. Water planes may be used not only for inspecting and surveying timber lands and making surveys for railroad construction, but for the transportation of mail, express, passengers, furs and supplies to places which are today inaccessible, but which may develop into large communities through airplane transportation. At present 12 patrols are operating daily in California and in Oregon to locate forest fires and reporting them by wireless telephone. The Department of the Interior states that this service is saving hundreds of millions of dollars yearly for the United States, and that plans are being laid for wide expansion.

One of the most valuable uses of the airplane will be for mapping. Photographic mosaics of parts of the country otherwise inaccessible have proved to be absolutely accurate and are in each case up-to-date. In projects for railroad construction airplanes will be employed for topographic work. Accurate topographic surveys can be made by airplane in a few hours, at a rate of, say, $15 per sq. mile, which it would take months and in some cases even years to make by ordinary surveying parties. In many cases these maps would be absolutely impossible

except for the airplane; certainly, their completeness of detail could not otherwise be approached. Daily aerial photographs of the freight yards in large railroad centers would give a much more accurate, complete and less expensive record of the location of freight cars. Officials, inspectors, supplies and mail can be transported through the air to inaccessible places where mining, timber or waterpower enterprises are under way. Even the transportation by air of valuable ore from some localities is being considered the quickest and least expensive method. An airplane can cross the Andes Mountains in South America at any point in 2 or 3 hr. Any other method of communication or transportation requires many days and sometimes several weeks. Deep-sea fishermen find that they can save time and money by locating schools of fish from seaplanes. Owners of large farms will make crop surveys at frequent intervals by airplane. In Texas airplanes are being used on large cattle ranches for locating breaks in fences and for finding and herding cattle.

Railroad companies may maintain airplane services to transport surgeons in case of wrecks and to convey injured persons to hospitals. Surgeons and specialists in the medical profession may often save lives when hurriedly called to another town, if they do not wait for slow trains. The relatives of those who are dangerously ill will use aircraft in a similar way. The delivery of city newspapers will be expedited and the aerial transportation of fresh meats, sea food and perishable fruits may prove to be profitable. Smuggling by airplane will be a menace to our borders, and the only means of prevention will be by airplane.

Although we are not going in for air transport seriously in America, as are England, France, Holland and Germany, we have in many ways more to gain than they have. Comparatively, we have tremendous distances to traverse, without complicated international agreements restricting the crossing of borders and landing on foreign territory. Again, our passengers need not be delayed and irritated by waiting for passports and customs inspections, which is really an important consideration.

Regarding the so-called sporting phase of aviation, there is fun in flying, a sense of power and thrills for the young man, but this phase does not help business unless we consider it as recreation or relaxation. The man off for a holiday can visit places which otherwise would require too much time. For instance, a business man might come from Detroit to West Baden often for the week-end if he could make the trip in several hours of exhilarating flying instead of taking a long, weary nerve-racking trip by dusty motor car or smelly train. A man in New York City might go deep into the woods for hunting or fishing if, instead of a week each way, only a few hours were required. He would see country he had never seen before, and from an entirely new point of view. The man whose office is in the heart of a city might consider the location of his home in an entirely different light if he could travel 50 miles into the country or along the shore in ½ hr.

The Impediments to Commercial Air Transport

In view of all these possibilities, why then has air transportation not been successful to date? What must we wait for before it can be a sound commercial proposition? A cautious business man may agree that these theories sound logical, but he will insist on knowing whether commercial aeronautics is a sound business proposition from the standpoint of returns on the investment. We are forced to admit that no air-transportation project within our knowledge has proved to be a paying proposition. To the question as to why a scheme that looks so promising cannot be made to pay, one man may answer that the general depression in business and financial circles makes people afraid to take hold of new things, especially if they are uncertain things and lacking in precedent. Another may say that with such a new and little understood device there is an inevitable period during which people must be educated up to it. People are instinctively afraid to get more than one foot off the ground, and this fear is fostered by the newspapers, which headline every airplane accident.

Let us not forget that the airplane is only 12 years old. The first steam locomotive ran on a track in Scotland in 1814. In 1829 there were 16 miles of track and one locomotive in America, and the first trans-continental track was completed in 1869. About 1860, when Pullman cars were proposed for comfortable night travel, an effort was made to pass a law prohibiting night trains as being too dangerous. In 1889 the telephone was 12 years old, and yet no one took it seriously. In 1897 the motor car was 12 years old and was looked upon with almost superstitious horror. Our forefathers were perfectly happy without these things but, today, we could not be. After the invention of the locomotive, it took 50 years for the railroad to start making money. The automobile, born 71 years later, began to pay in only 20 years. This is an era of industrial expansion, of progress in the scientific and commercial world, and the public is learning to take to new things more quickly. Nevertheless, to commercialize the airplane it is imperative to overcome the inertia of that inherent prejudice in the minds of the people against new things that they do not understand. There is a logical development period for this, as well as for any other sound business. Airplane companies have failed in trying to force airplanes on the public for commercial use before the people had any conception of the possibilities and the limitations of this new vehicle. The records prove that automobile companies had the same experience. The fear and inborn conservative prejudice against new "contraptions" cannot be discounted. Any enterprise whose leaders do not consider this phase is not sound. The vision of the directors is ahead of their business judgment. Those who risk capital in a high-sounding stock-jobbing enterprise starting on a large scale at this time, expecting immediate returns, are unfortunate.

Safe and Reliable Airplane Service

Before air transportation can be made to gain and maintain the confidence of possible users, it must be made safe and reliable. Here again one must admit that a regular scheduled service cannot be called safe and reliable until the engineer and the scientist have carried development further. For instance, any supposed expert who advises a prospective investor that safe and accurate airplane navigation and landing in thick weather and at night are assured today is doing the science infinitely more harm than good. It is only by telling the truth, even leaning toward the ultra-conservative, that we can consistently keep the confidence of the people. At a recent meeting in England the official announcement that from May 1919 to December 1920 inclusive 106,712 passengers were carried on 62,003 flights out of foggy London, covering a total distance of 1,556,000 miles and with only eight fatal accidents, in which one passenger was killed for every 10,000 carried and one was injured for

every 7000 carried, met with wild enthusiasm. This enthusiasm was sadly dampened when it was pointed out what a terrific loss would be recorded in railroad travel if the same percentage figures were to obtain.

The essential elements for a safe and reliable airplane service which is to operate either on regular schedule or under such provisions that a trip can be made at any time are included in a consideration of the airplane itself, its engine, its pilot, landing fields, the weather and navigation aids.

Considering first the airplane itself, a modern machine intelligently designed, well built of the proper materials and carefully inspected and maintained, can be made to fly safely over level open country. Under normal conditions there is almost no danger of structural failure of any part, of fire or any mysterious tendency to get beyond the control of a good pilot, either with the engine running or when it is shut off. One cannot say, of course, that the airplane of today is the perfected machine of the future, even as regards general outlines. In 10 years we may have a wholly different machine. Although we can now make airplanes that are comparatively fast and sufficiently strong, stable and controllable, we have seen nothing that looks like, or appears to the man who must take care of and repair it, or sells like a commercial article. The present airplane costs too much; requires too much time to build; has a construction not adapted to quantity production; is complicated to care for; is flimsy and goes to pieces rapidly; will not stand rough handling or weather; requires a large field from which to operate; uses too much gasoline and oil; is clumsy to transport when needing repairs; demands too long a time to remove or adjust the engine; and will not travel far enough or carry enough load.

As to the talk of giant airplanes capable of carrying a ship-load of passengers across the ocean within a few hours, one hesitates in this age to say that anything is impossible; but it is safe to say that, with such types of powerplant and methods of airplane construction as have been suggested and appear feasible, the airplane cannot handle more than say 6000 ton-miles of commercial cargo in competition with lighter-than-air craft. The increase, with size, of unit weight of sustaining surface alone appears to establish some such limit. Non-stop transoceanic flights by airplane would be extremely expensive, in view of the very small number of passengers possible. On the other hand, the airship appears, theoretically, to become more economical with increase in size, and will without doubt be used in transoceanic service. It cannot however, compete with the airplane in carrying comparatively small loads for short distances, either as regards cost or speed; for instance, 1 ton for 300 to 400 miles. In transcontinental service, with small loads, the airplane will beat the airship for cost and speed, even though the cargo must be relayed. The fields of utility of the airship and the airplane will not overlap.

First, let us try to build one of three types of airplane, each capable of safely getting into and out of comparatively small fields and having cruising speeds of 100 m.p.h. with cargo capacity and flight range such as (*a*) 600 lb. or three passengers, for 400 to 500 miles; (*b*) 1200 lb. or six passengers, for 300 to 400 miles; and (*c*) 2 tons, or 20 passengers, for 200 to 300 miles. Before we go further, let us learn to build such airplanes so that the cost of building, operating and maintaining them is not all out of proportion. When this is accomplished, a long step toward making a success of commercial aviation will have been made.

The advice has been given to sacrifice all else for speed, because speed is the raison d'être of the airplane. Speed is essential when bucking a head wind, but what good is speed if the cost prohibits its use? Consider a 200-mile trip. Our 100-m.p.h. machine makes it in 2 hr. A 150-m.p.h. machine does it in 1 hr. and 20 min. By train, over a curving route covering 250 miles, from 6 to 24 hr. is necessary. By automobile, from 9 to 12 hr. is required. The loss of 40 min. can be neglected, especially if the landing field at either end be a 1-hr. drive from the center of a city; it seems that other things are of more immediate importance.

There is much discussion as to whether commercial airplanes should be radically different from modified war machines. Regardless of the merits of the arguments, the fact is that almost all of our so-called commercial airplanes of today are modified war machines. One might venture the statement that a successful commercial machine must be wholly different from its military predecessor in that it must be cheaper and simpler. In war, the speed of an airplane, its ability to climb to great altitudes, its maneuverability and armament, must all be better than similar characteristics of the enemy's machines, regardless of cost or complications.

A phase worthy of thought is that during the war, when money was of small account and time was everything, immediate practical application at the sacrifice of research was the pressing need. It is perfectly natural that things seem to have gone slowly since the armistice. Our mental processes have not had time for readjustment. The result is that we have not got down to thorough research on the fundamentals. Problems upon which we had just begun research work before the war are not much further advanced today. Since the war, a great part of the energies of the members of the aircraft industry has been spent in endeavoring to realize financially on products constructed during the war, by trying to adapt them to civil uses. Such efforts are of course expedient, but the result has been that we still try to think of commercial aircraft in terms of war machines. Again, it is important to keep in mind the probability that air-transport companies have been forced to make the type of service, the routes and the points to be connected fit the machines available. The result may be that the logical routes for economy in business have been neglected. The present time should be considered the logical period for development. One might venture the suggestion that unless there be real danger of a national emergency in the near future, the Government should expend its funds during this period upon research, experimental construction and development, rather than upon a more than very limited production; but, in doing so, so far as may be in the interests of national economy, it should help to maintain facilities for future production by making such experimental work profitable to the industry. This appears to be purely a matter of national insurance.

Referring again to the cost of construction, the American manufacturer will say that quantity-production methods will accomplish the desired result. Here, then, is one problem which the engineer cannot solve without help and that help is not yet at hand. To illustrate, consider metal construction, which is undoubtedly better for rigidity and for endurance in varying climates; clever design for American production processes would certainly bring the cost of manufacture down considerably; but no manufacturer can afford to tool-up to build just a few machines and without such tooling wood is cheaper than metal. In this respect the engineer has arrived at an

impasse. Airplanes cannot be cheap until there is a demand, and there may be no demand until they are cheap. This is one answer to the query as to why we must wait for airplane development. However, let us remember that the automobile industry met and overcame this obstacle in time.

The airplane engine is probably much further developed than the airplane; aside from a radical change in principle. Consider some of the performances of airplane engines as indicative of their reliability, such as Alcock's flight across the Atlantic; the trips of the NC flying-boats; the flight of four machines from New York to Alaska and return; the flights from London to Australia and to Cape Town; our daily mail service from coast to coast and the crossing of the Rocky and Sierra mountains; the circling of the rim of the United States, and Coney's flight from coast to coast in two hops. Our best airplane engines can be said to be reliable from the standpoint of mechanical operation. Most of the forced landings are caused by stoppages in the fuel lines or in the carbureter jets, sometimes by leaks in the cooling or oiling systems, and by ignition troubles. However, lest engine designers wax complacent, let us reiterate, airplane engines cost far too much.

The development of pilots is the easiest problem of all. The war proved that among the young men of America there is no dearth of those of natural aptitude for flying, whose determined spirit, tempered by cool judgment and resourcefulness, make them ideally adapted to the work. To be sure, experience in navigating 'cross-country and in judging the approach to a bad field is essential.

Landing Fields

If the airplane designer keeps other things equal, such as engine power, empty weight and aerodynamic efficiency, the higher the flying speed is, the larger must be the field to land in safety; and the greater the load is, the larger must be the field to get out of safely. It has been maintained rightly that air transportation cannot become a fact until our cities and towns have landing fields. Here, again, we have arrived at what appears to be an impasse; temporarily at least. Before they vote for a municipal landing field, the men who are interested in the commerce of a given city must be convinced that the cost of purchase and maintenance will be more than balanced by the profit to the city's commerce. We may accuse them of lack of far-sightedness but, after all, is it not incumbent upon us to prove to them that air transportation will pay? The cost of landing fields at each of two cities, say 300 miles apart, is negligible as compared with the cost of a highway or a railroad connecting the two. The city gets all of the benefit of a landing field, whereas the benefit of a road is distributed along its entire length. From this is appears that the man in business in the city should be more interested in aircraft than the farmer.

Some of the requirements of a landing field are that

(1) It should be located so that the time required to travel to and from the business district of the city is as low as possible. Airplanes will not save nearly so much time when they connect two towns 100 miles apart if an hour is spent in getting to and from the airdromes. We can send mail to and from landing fields by pneumatic tubes, but it would be too expensive to send passengers in this way. It has been suggested that machines land on the flat roof of a large building. While this may eventually become safe and practical, it should not be permitted at this time

(2) The field should constitute an area of at least 50 acres of smooth level ground if there are no obstacles immediately adjacent. If there are surrounding obstacles, such as hills, buildings, trees and high-tension wiring, it should comprise at least 100 acres. These figures are minima; the larger the fields are, the safer they are

(3) The ground and subsoil should be of such nature and so drained that the field is never swampy or muddy

Regarding ways and means of financing a municipal landing field, it has been suggested that each municipal flying field be used as an Army reserve pilots' school, in addition to serving as a station for commercial transportation lines. Then that the Government pay a small percentage of the purchase price of approved fields; that the city pay the remainder; and that transportation companies be charged rental for land upon which they build hangars and shops and for the use of the field. Further, that Army reserve and student reserve pilots form a club and pay for building a clubhouse, except for a small percentage paid by the Government, and that the club be supported entirely by its members. In addition, that the Government furnish training airplanes, pay for the erection of hangars and shops for its own airplanes; and, for military training, pay for fuel and repairs. Some such scheme might prove most economical and effective in maintaining a large force of pilots in the event of a national emergency, at the same time lending Government aid to start aviation. France has gone further in her efforts to popularize aviation. On Sundays and holidays, according to reports, the Government airdromes are thrown open to the public and pilots, known to be qualified, are permitted to use the Government machines free of cost.

The Weather and Navigation Aids

We have seen that it is possible at present to control four of the elements essential to successful commercial flight, the airplane, the engine, the pilot and the landing field, in such a way that air transportation can be rendered at least sufficiently safe and reliable to warrant the confidence of the public, although it is not by any means perfect as yet; but it is not yet safe to fly 'cross-country in thick weather, in clouds, fogs, rain or snowstorms. We cannot control the weather and must learn to circumvent it. One might venture the statement that no form of transportation can become a really serious factor in the world's commerce unless trips can be made to any desired place in any sort of weather. A company cannot possibly afford to maintain expensive equipment unless it can guarantee service whenever required. The possible user must know that aircraft can transport him or his goods faster at any and all times than in any other way; he must be taught the habit of thinking of the matter in this way. A railroad cannot be successful if it has nothing but engines, cars and tracks; the telegraph, the telephone, block-signal systems, and automatic stops and switches are absolutely essential to its safe and reliable operation. Yet, just because the present airplane can cover the distance between two points many times as rapidly as any other vehicle, some people seem to feel that we are ready for commercial aerial transport.

There appear to be two big problems incident to all-weather flying; (*a*) we must fly when there are clouds or storms and because it is dangerous to fly in clouds, and often dangerous and fatiguing to fly below them, we must fly over them and develop means to navigate accurately; and (*b*) we must develop means to find a landing

station and to effect a safe landing on it, when fog extends down to the ground. These problems seem to offer tremendous difficulty but not until they are solved can we deserve the confidence of the public when talking of commercial aerial transport.

Gyroscopic compasses and turn indicators, if sufficiently accurate and reliable under various flight conditions, would assist greatly when flying above the clouds. A simple and practical bubble sextant for the observation of heavenly bodies might be useful on long flights. But these, even though they be made to function with perfect precision, will not suffice. Before air transportation can be a big thing, we must dot the country with radio "lighthouses," unless some better scheme be developed. In addition, airplanes should be equipped with wireless telephones and the ground stations with directional wireless sets. Simultaneous readings of direction of the aircraft would then be taken by two or more ground stations, the latitude and longitude would be determined by plotting to get the section of azimuth lines, and the airplane pilot would be kept informed continuously of his location. The most economical distance between ground stations must be determined through actual service. There must be no danger of interference between these and other radio sets; this should be regulated by Federal law. The cost of installation and operation of such ground stations will be negligible as compared with that of railroad telegraph and block-signal stations. Some such system, or a better one to accomplish the purpose, is just as necessary to successful navigation of the air as the airplanes themselves, not only for flying in thick weather but also at night.

Landing in Thick Weather

This promises to be a much more difficult problem, but it is just as important of solution. There are two phases to be considered (*a*) finding accurately the regular airdrome, gliding into it so as to cross its border at the correct altitude and in the right direction and landing safely without striking an obstruction; (*b*) landing safely and avoiding dangerous obstacles, when a landing while lost in the fog is unavoidable through failure of the powerplant.

It appears easily possible to develop means to indicate to the pilot, while he is flying in a thick fog, when he has arrived in his glide at the proper height above the ground. This is all very well, provided one is landing on a perfectly smooth unobstructed surface; but what appears at present to be almost impossible is to insure against collision with some dangerous obstacle when landing in a dense fog in strange country. We may eliminate all of the other dangers of commercial 'cross-country flying in the near future, but this one may remain. But let us remember and take heart, for if we have a reasonably reliable powerplant, reserve fuel and means for accurate navigation, we can discount the possibility of forced landings in strange country. Nothing is 100 per cent safe. We do not worry about travel by train or motor car, although statistics have shown and continue to show many serious accidents. Records show that 11,000 deaths resulted from automobile accidents in the United States in 1919.

The first phase of this problem is a difficult one, that of landing at a regular station in a fog. It may be possible to dispel or precipitate a fog for a few minutes over a small area and to a height of say 200 ft. However, methods so far suggested for accomplishing this are prohibitive because of their excessive cost. Special radio "localizers" and sound signals, such as the rapid firing of a gun, supplemented by the radio telephone and by powerful searchlights throwing beams of peculiarly penetrative qualities, have been suggested; but we know of no really satisfactory development. Continuous meteorological reports, transmitted from Weather-Bureau observation-stations to the airdromes, the ground radio stations and thence to the airplanes in flight, will be necessary. Rules must be developed that are more dependable than at present for determining the direction and velocity of wind currents at various altitudes, and for predicting storm paths. The Weather Bureau might use self-recording meteorological apparatus elevated by kite balloons at their observation stations. A real aid in 'cross-country flying would be to have the names of the towns and villages painted in large type on the roofs of the railroad depots or the largest buildings. Illustrating the apathetic attitude of the public toward aviation, possibly an excusable one, it has been found impossible to persuade the towns to do even this much. Some conception is thus afforded of the complexities and expenses incident to an air-transport service, but the problems are by no means solved as yet. The scientist and the engineer can go far toward solving them, in the laboratory and at the experimental flying station, but, after all, will not the final solution come only after continued tests in actual service? This has been proved in the development of the motor-car and of all such mechanical systems. As a matter of fact, the engineer cannot get a real conception of the problem before the particular device has been tried out and its weaknesses developed under hard practical service conditions.

The first route used to develop means for navigation and landing should be of such nature as to typify the hoped-for eventual lines; that is, it should be at least as difficult as the average. The equipment for flying and the apparatus and facilities on the ground should be complete and, because most of them are experimental, subject to constant change. Such a project, if it is to give the real solution, will require not only time, experience and the efforts of capable scientists and engineers, but a large amount of money expended by wise business administrators.

The Financial Aspects of Aviation

As to whether present conditions in this country are such that a cautious business man, a possible investor, will go in for such an enterprise, once more we seem to be at the end of a blind alley. We have tried to show that an air-transport service projected now must operate at a loss for a year or two at the best, because it would not have nor deserve the confidence of possible users until further developments have been perfected; and yet, before aviation can get on its feet, there must be at least one line operating continuously for a long period. This is necessary not only to develop apparatus but, equally as important, to instill into people the habit of taking air transport seriously, gaining their confidence.

Let us analyze the reasons back of the refusal of conservative business men to go in for aviation. Assuming that there are in this country many men of means who believe in the future of aeronautics and have sufficient vision and far-sightedness to be enthusiastic over it, we will confine our analysis to this class. First, many of these men feel that they have not the time and others have their capital tied up in some enterprise which promises quicker and more certain returns. But supposing there are men in this country who are willing to lose

money on such a project until the time when the education of the public meets mechanical development, the odds are against their going in for it. The absolute lack of Federal legislation controlling or regulating civil aeronautics is an unsurmountable obstacle. The administrators of any enterprise could have no confidence in their position before this condition was remedied.

As an illustration of the dangers incident to the lack of Federal control, no measures exist to prevent any person who represents himself to be a pilot and an engineer from buying or even building any sort of airplane, setting it up in a vacant lot and starting to carry passengers wholesale. The airplane may be dangerous for one or more of many reasons; the original design may be bad from either aerodynamic or structural considerations; the workmanship may be amateurish or the material weak. Our so-called flyer may leave his machine exposed to the weather and to the tampering of the townsmen and, either through ignorance or carelessness, the inspection and maintenance may be ineffective. The field may be small or surrounded by dangerous obstacles. The flyer himself may be reckless, or lacking in skill, or both. Could one acquainted with aviation do otherwise than wax vehement in protestations against his friends taking airplane rides under such conditions? It is marvelous that the number of accidents, not only to passengers and to people swarming over the field, but to those on the streets, are not more numerous than they are. There is no law to prevent the unscrupulous promoter from exploiting the amateur designer or the inventor, and soliciting stock subscriptions for a visionary enterprise which can have no hope of success and does well if no innocent passengers are killed during trial flights. How can a serious enterprise be promoted when such conditions exist? Insurance rates must remain prohibitive and even though a legitimate air-line might operate for several years with 100 per cent of safety and reliability, it cannot hope to maintain the confidence of the public if accidents continue because of the operations of irresponsible and uncontrolled amateurs.

Sensible and comprehensive laws are of immediate importance; laws enforced by capable inspectors controlling the original construction, the maintenance of the equipment, the personnel, including the pilots and mechanical forces and the scope and methods of operation of all aeronautic enterprises.

At present the Army, Navy, Marine Corps, Post Office, Geological Survey, Coast and Geodetic Survey, Forest Patrol, Customs and Coast Guard are more or less interested in aeronautics. It appears that there is little co-ordination of their aeronautical activities. As a result there must be duplication of effort and loss of money.

Government Aid

We have seen that any group of men undertaking an air-transport enterprise at this time must be prepared for heavy financial losses, for a time. Perhaps there is no group of men in this country that is willing to undertake such a project and capable of carrying it to success. In this connection, the unfailing optimism and generosity of men like Mr. Uppercu, of the Aeromarine Co., are doing much to pioneer civil aviation in this country. The consensus of opinion among the more progressive military experts appears to be that the next war will be won in the air. If the United States is to be prepared, we must not lag in aeronautic development. We must also be ready with plant facilities and trained organizations for building up-to-date aircraft. It is a duty to carry insurance for our Nation in this way; perhaps our taxpayers cannot afford to maintain huge military air fleets in peacetime because they represent an investment for which there is no possible return until war occurs. A less expensive way of pushing development and of maintaining facilities against an emergency might be for the Government to help legitimate commercial enterprises until they can stand on their own feet.

France, evidently appreciating the national value of aviation, has gone in for governmental subsidy, even in her present state. For the fiscal year 1921-1922 the French Parliament voted $6,500,000 to be used entirely for helping commercial aviation. The subsidies to be granted are a subsidy for purchase and a subsidy for public transport. Subsidies will be granted only to French subjects and companies employing French material and French pilots and personnel. The subsidy for purchase consists of a grant by the State of half the value of machines employed for transport. No subsidy will be given for aircraft built before July 1, 1920. The purchaser receiving the subsidy must undertake to keep the machine in good condition and guarantee that he will not sell the machine or allow it to leave France without special consent. The company must own such a number of airplanes that there will be one machine for every 100 flying-hr. expected. It must employ at least one pilot for every three machines and one mechanic for every 300 hp. utilized. In addition to certain grants for purchase and for depreciation, for the pay of the crew, the cost of fuel and the like, the Government pays 9 cents at the present rate of exchange for every passenger-mile, and the passenger pays 9.5 cents per mile. For goods carried, the Government pays 0.00275 cents per lb.-mile, and the shipper pays 0.0825 cents per lb.-mile. But, although our Government helped the railways to start, by condemning and granting them great stretches of land, and helps merchant vessels by maintaining lighthouses and lightships, the direct subsidy of aircraft is not countenanced. A subsidy has many disadvantages, not only to the Government but to the corporation, and a subsidized enterprise is not a healthy one. This form of aid may, then, be eliminated.

The Air Mail

The most logical form which Government aid can take appears to be the letting of definite contracts to responsible corporations for the delivery of mail. Let this be done on a really big scale by forming a network of air-mail routes covering the entire country. Bring places now inaccessible into touch with the world and do not confine aerial-mail routes to cities which already have fast and frequent train service. Reach the places, rather, which have very slow mail service at present. Let the contracting companies be paid at a sufficient rate to insure them against loss, with additional bonuses for exceptionally good records for regularity and consistent speed.

Suppose we grant that the Government will, for a few years perhaps, lose money in endeavoring to carry mail in this way. The delivery of mail will be expedited at least, if capable people handle the service. The important point is that our Government would be fostering development, and maintaining facilities for the production of aircraft in the event of an emergency, at comparatively small cost. In a short time, the companies operating the various lines will have developed means for flying regularly and economically with a high degree of safety and reliability.

Underlying Principles of Electrical Ignition

By Benjamin F. Bailey[1]

Detroit Section Paper *Illustrated with* Diagrams

MY purpose is to point out some of the underlying facts that we must consider in connection with electrical ignition. I shall try to make them plain by the use of some analogies with mechanical things. Let me speak first about the simplest form of electric ignition, one that is now practically obsolete but formerly was very common. Fig. 1, at the left, shows the circuit of the old touch-spark or wipe-spark ignition. A battery is shown at *a*, a coil of wire wound around an iron core at *b*, and at *c* a contact-breaker which opens and closes. The iron core consists preferably of a bundle of iron wire. In this type of ignition that contact breaker is located inside of the cylinder and is opened and closed by the motion of the engine. There is also a switch *s* on the outside to turn the ignition off and on. There is a very close mechanical analogy between this circuit and an automobile starting under the influence of a constant force. At the right in Fig. 1 the car is being accelerated from rest by a force applied in the direction *a b*. This corresponds with the electromotive force applied by the battery to the coil.

In the electrical device we have current; in the automobile we have velocity. The velocity of the automobile corresponds with the velocity or speed at which the electricity is moving through the circuit. The mass of the car corresponds with what we call the inductance of the coil; and, lastly, the friction of the car corresponds with the resistance of the electric circuit. The car resists being moved on account of friction. Electricity resists being moved due to resistance. We have what we call inductance in the electric circuit. If an attempt is made to change the velocity of the car, the change is resisted by the inertia of the car. Similarly, any change in the current through a coil is resisted by the inductance of the coil. If the circuit be closed, a current

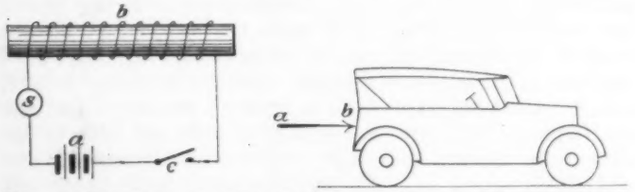

Fig. 1—Diagram of the Old Touch-Spark Ignition Circuit Which Is Analogous Mechanically to an Automobile Starting under the Influence of a Constant Force

passes through the coil and sets up a magnetic field. As the current grows it sets up lines of magnetism through the iron core. As these lines grow they induce in the wire an electromotive force which resists the rise of the current. The system is conservative and always resists any change. If the current is flowing it dislikes to stop and if it is not flowing it dislikes to start. In that respect it is exactly analogous to the automobile, which resists being started and requires brakes to stop it. This growth of the magnetic lines explains why we have an inertia effect in electric circuits. Applying a constant force to the car at the right in Fig. 1 would be analogous to applying a constant electromotive force to the coil at the left in Fig. 1. In the case of a car it will start, accelerate gradually and finally reach a certain definite limiting speed when the frictional resistance is just enough to balance the force. If we plot the curve of velocity and time, as in Fig. 2, it will rise and finally become horizontal. The final value will depend upon the frictional resistance and the force applied. In the case of the electric circuit precisely the same thing happens. The current starts, rises and gradually attains its final value, which is determined by the resistance and the electromotive force of the circuit. In the mechanical case we have the velocity finally equal to the force divided by the friction. In the electrical circuit we have the current, represented by I, equal to E/R. In neither case is the velocity or the current attained instantly. It takes time to do it. The exact expression for this curve is as follows:

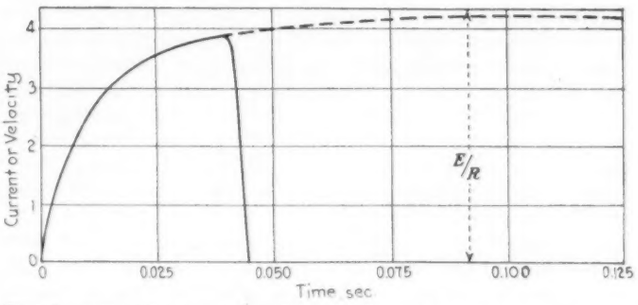

Fig. 2—Curve Showing the Time Rate of Growth of an Electric Current or the Velocity of a Car Accelerating Gradually

$$I = E/R\ (1 - \epsilon^{-Rt/L})$$

in which

I = the current at any instant
E = the electromotive force of the battery
R = the resistance of the entire circuit
L = the inductance
t = the elapsed time following the closing of the circuit
ϵ = the base of the Naperian system of logarithms

The instantaneous value of the current at any time is equal to the electromotive force divided by the resistance, multiplied by a reducing factor. As time increases the reducing factor increases, the value finally reaching unity. The current then equals the electromotive force divided by the resistance.

The analogy can be carried further. As we accelerate the car, we expend energy and the car acquires a certain store of energy. As we increase the current through the

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induction-coil we are similarly storing energy. The expressions in the two instances are again analogous. In the case of the car we know that the energy stored is equal to one-half of the mass of the car times the square of the velocity. In the electric circuit it is one-half of the inductance times the square of the current. The corresponding mathematical expressions for the stored energy are $\frac{1}{2} Mv^2$ and $\frac{1}{2} LI^2$. If we stop the car suddenly with the brakes, what happens? We increase the friction by putting on the brakes. In the case of the electric circuit, we have a similar thing. When we open the circuit that does not mean that we stop the current instantly, but we introduce the resistance of the air-gap which, comparatively speaking, gradually stops the current. The current in stopping follows a curve similar to that which the car follows while it is stopping. In either case the energy must be expended somehow. With the car the brakes get hot. In the case of the electric circuit the energy is expended in the gap and the gap gets hot; in other words we have a spark there which is capable of igniting a mixture of air and gasoline.

We also can extend the analogy to the force that is developed by the stopping. In the case of the car, if we try to stop it suddenly the force required is very great. If we stop it gradually, a much smaller force will suffice. In the case of the electric circuit, if we open up the gap rapidly there is a large induced electromotive force, just as though we had stopped the car suddenly, for instance, by a collision. The more sudden the stopping is, the greater the force will be. So, the more quickly the gap opens the higher is the electromotive force that will be developed. This system has become more or less obsolete, although it has great advantages

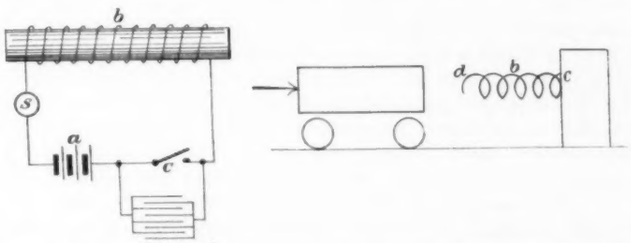

FIG. 3—DIAGRAM OF AN ELECTRICAL CIRCUIT IN WHICH A CONDENSER IS INTRODUCED AND THE CAR IS CONSIDERED TO STOP BY STRIKING A SPRING RATHER THAN BY APPLYING THE BRAKES

in its favor. It is unquestionably the simplest device from the electrical standpoint, but the mechanical complications, such as the difficulty of keeping the points in order, have caused its disuse, except perhaps for large stationary engines.

A slight modification brings us near to what we have in the secondary coil, or the regular induction-coil. If we shunt a condenser across c in Fig. 1 we have the arrangement shown at the left in Fig. 3. A condenser is built up of a series of sheets of tinfoil or similar material, separated by an insulating medium. The current cannot pass through the condenser because of the insulating material between the plates. A certain amount of electricity can, however, be stored in a condenser. The amount is proportional to the force applied to push it in; in other words to the electromotive force.

We can represent an analogous set-up in the case of our car. Instead of putting on the brakes, we will allow the car to hit the spring shown at b in the right portion of Fig. 3 which is fastened at the point c and loose at the point d. Closing the contact c at the left in Fig. 3

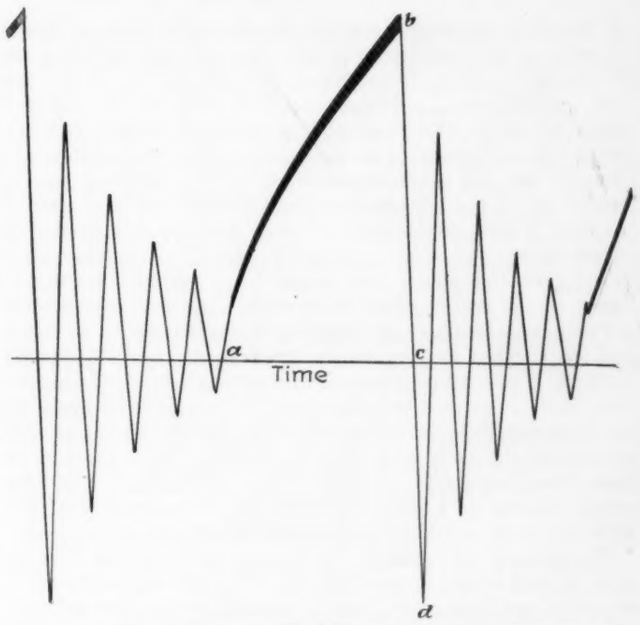

FIG. 4—DIAGRAM SHOWING THE OSCILLATION OF AN ELECTRIC CURRENT WHEN THE CIRCUIT IS OPENED

is analogous to giving the car at the right a push. Opening the contact c is equivalent to allowing the car to hit the spring in Fig. 3 and become attached to it. The analogy between the spring and the condenser is perfect. The distortion of the spring is proportional to the force applied to it and so is the distortion in the electric condenser; that is, the quantity of electricity that is stored in the condenser is proportional to the force applied to accomplish this result, just as the distortion in the spring is proportional to the force applied to it.

Suppose the car goes up against the spring at b and is coupled to it in some way so that it cannot get away. It will compress the spring, shoot back, go forward and keep oscillating until the friction finally brings it to rest as shown in Fig. 4. Exactly the same thing happens in the case of the electric current. We close the circuit, which corresponds to starting to push the car. The velocity increases as shown by the line $a\ b$ in Fig. 4. At b we open the circuit, which is analogous to having the car hit the spring. The current is brought to zero rather quickly, but it swings past the zero value, increases to a negative value of $c\ d$, again decreases, reverses and so on, oscillating in this way for some time. We can control the frequency of electric oscillation in the same way that we can control the frequency of oscillation of the car, or just exactly as we can control the period at which a car bounces on the springs when it hits a bump. There is absolutely no difference between the two phenomena.

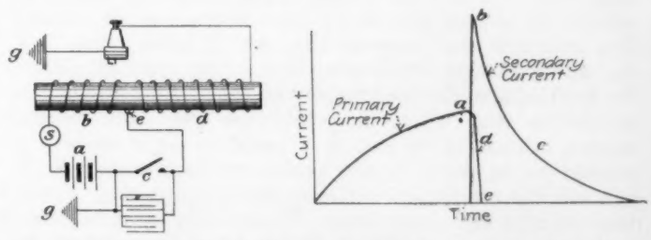

FIG. 5—DIAGRAMMATIC VIEW OF A TYPICAL IGNITION CIRCUIT IN USE AT THE PRESENT TIME AT THE LEFT AND AT THE RIGHT THE CURVES OF PRIMARY AND SECONDARY CURRENT

If we want the oscillations of the car to be slow, we make it very heavy, or use very flexible springs, or do both. If we want them to be quick and sharp, we make the car lighter, or the springs stiffer. We do exactly the same thing in the case of the electric circuit. If we want the oscillation to be quick, we stiffen the condenser; that is, we use a condenser that will not store so much electricity for a given force, just as we stiffen a spring so that it will not deflect so much for a given force; in other words, we use a smaller condenser. Another way to quicken the oscillations would be to reduce the inductance of the coil *b;* that is, to reduce the property which corresponds to mass by putting fewer turns on it. We can go further and calculate the frequency of the oscillations, if we know the constants involved in the problem, just as we can calculate the frequency with which a car will oscillate when it hits a bump, if we know the weight of the body and other constants. As a matter of fact, these electrical oscillations generally require in the neighborhood of 1/3000 sec.; that is, there will be about 3000 complete oscillations in each second.

To modify the simple diagram shown at the left in Fig. 3 and make it correspond with the coils that we actually use today, we put a secondary on the coil as shown at the left in Fig. 5. The secondary winding is usually wound over the primary winding, but is drawn separately to simplify the diagram. If we close the circuit at the left in Fig. 5, the current will rise in the primary of the coil. This means that the magnetic lines will increase in number in the coil, starting from zero. This will induce electromotive force in the secondary of the coil, at the "make." However, the rise is fairly slow. The electromotive force induced is dependent on the rate at which the magnetic lines are cut. If we cut the lines slowly, the electromotive force is small; if we cut them fast, it is high. Hence, the electromotive force that we get in the secondary of the coil is comparatively small. It is small enough that the spark cannot jump the gap on the spark-plug. If we had no spark-plug, we would have the current flowing in the secondary at the make but with the spark-plug there we get no current if everything is all right. When we reach the point *b* in Fig. 4 and open the circuit, if the condenser is properly adjusted, the rate of cutting of the magnetism will be exceedingly rapid, and consequently a very high electromotive force be induced. If no current flows through the circuit, for example, if the wire is detached from the spark-plug, the primary current will continue to oscillate, just as it did without any secondary winding on the coil, and we shall have an oscillating secondary electromotive force. But ordinarily that is not what we get or what we want. As a rule, we have enough electromotive force in the secondary so that the current jumps across at the spark-plug gap at the left in Fig. 5. In this case we have little or no oscillation. It is perhaps difficult to understand why this is so but, as soon as the spark jumps, it begins to absorb the energy that was stored in the electric circuit. The action is the same as that which takes place in a car equipped with shock-absorbers. The friction resists the motion, absorbs the energy and therefore kills out the oscillation that we would otherwise get. So, in the electric circuit, if we put in a resistance and allow the current to do work, if the resistance is low enough it will kill the oscillation entirely; the current then comes down to zero and stops there. Practically, we never succeed in transferring all the energy from the primary to the secondary of the coil. We always have some oscillation left. The curves of primary and secondary current are shown at the right in Fig. 5. The secondary current is much smaller than the primary, but is here plotted to a larger scale to make the diagram clearer.

What happens in the secondary is exactly what will happen if we have our car in motion, shut off the driving force and allow the car to coast. It will slow down gradually until it comes to a stop, and follow a curve very much like the curve of the secondary current, shown at the right in Fig. 5. The primary current is large; in an average coil it would amount to from 2 to 5 amp. at the point *a*. In the secondary the current at *b* would be perhaps 0.1 amp.

Curves like those of Figs. 2, 4 and the one shown at the right in Fig. 5, are obtained by an oscillograph. The oscillograph is an ammeter with the parts made so light that they can keep up with the very rapid fluctuations of the current. When the current fluctuates very rapidly through an ordinary ammeter, the needle does not have time to follow and it will simply stand still and indicate an average value. In the oscillograph the moving parts are exceedingly light and have so high a natural period of oscillation that they can keep up with any ordinary variation. A very small mirror reflects a beam of light against a moving film and traces out its path along the film.

In the actual ignition system some other points must be taken into account. Fig. 6 shows the curve of rise of current in an induction-coil. We do not always get the same distance along that curve. If the car is standing still and the breaker-points on the ignition switch are closed, the current reaches the highest possible value which is E/R. But when the engine is functioning and the breaker-points are opening and closing rapidly, there will not be time enough to get full current value. If the engine is running slowly, we get say the value shown at *a;* if it is running twice as fast, we get the value shown at *b*, and if four times as fast, we get the value shown at *c*. The energy we have stored in the coil is equal to $\frac{1}{2} Li^2$, or one-half the product of the inductance and the square of the current, just as the energy stored in a moving car is $\frac{1}{2} Mv^2$. This means that we will not get anywhere near so much out of the coil at high as at low speed, because the contact is not closed nearly so long. Thus it will be seen that the faster the engine is running the less will be the energy stored in the coil each time the contact is closed. The energy delivered is less than the energy stored, but can be taken as roughly proportional to it. In Curve *I* of Fig. 7, the values of the energy per spark with the revolutions per minute of the engine are plotted. This curve is of course derived from Fig. 6. Its exact shape depends upon the characteristics of the coil, the number of sparks per revolution and the percentage of time that the breaker-points are open. The design must be such that the ignition is satisfactory at the highest possible speed of the engine. At the lower speeds the spark will then be somewhat stronger than is absolutely necessary.

Battery and Magneto-Ignition Similarities

The modern high-tension magneto has an induction coil with primary and secondary windings. The primary is short-circuited most of the time by contact points which open when the spark is to be produced. These points are shunted by a condenser. So far we have everything that we have in the battery system, except the battery. I said an induction-coil; it is actually called an armature, but it is the same thing, practically. It consists of some laminated iron around which two coils of wire are wound; one coil is

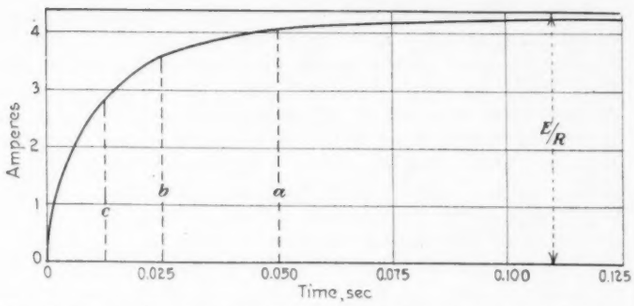

FIG. 6—CURVE SHOWING THE RISE OF CURRENT IN AN INDUCTION COIL

of comparatively coarse iron wire, and the other is of very fine wire. In that sense it is an induction-coil. Including the breaker, we have all the elements of the battery system, except the battery itself. We substitute for the electromotive force of the battery the electromotive force which is generated directly in the primary coil by the rotation of the magneto armature. The electromotive force generated by the armature of the magneto is an alternating one and not the steady, direct, electromotive force furnished to the induction-coil, because the magnetic flux is cut first in one direction, and then in the opposite direction, generating a to-and-fro electromotive force instead of an electromotive force in one direction. The fact that the current is alternating does not bother us particularly, provided we break it at or near the time it has its maximum value. If we should break it when it is down near zero, we would not get much of a spark, but if we break the current when it is near the top of its wave, the conditions are very much the same as in the case of the induction-coil system.

One point of difference which is rather insisted upon by the makers of magnetos is the fact that in the secondary we have not only the electromotive force which has been induced by the very rapid dying down of the primary current, but we have the electromotive force which is due to the cutting which continues after the points are open. The curve at the right in Fig. 5 shows how the primary current rises and then drops very suddenly, and how the secondary current rises very quickly and then tapers off. After the circuit has been broken, the secondary current is left entirely to itself. It is like a car that has been given an impulse, left to coast and finally comes to rest. That is not true with the magneto. We keep on applying a push to the electric circuits, just as though we had the clutch partially in on the automobile and applied a slight push instead of allowing it to coast freely. This is because we keep on generating electromotive force. The result is that the secondary magneto-current does not die down so rapidly as that from a coil. This effect is the so-called follow-over. It is the current which the magneto men say produces the "whiskers" on the spark.

We can now compare the current we get from the magneto with that we get from a battery-ignition system. The electromotive force in the magneto is supplied by its rotation. Obviously, if the magneto is standing still, there will be no electromotive force. Obviously also, as it speeds up, the electromotive force increases in proportion; so we have very much the same condition as if we had a battery-ignition system in which we started with very low electromotive force at slow speed and gradually increased it in proportion as the engine ran faster. Hence, instead of giving a constant push we give it a much harder push at the higher speed. The current in the magneto rises along very much the same curve as is shown in Fig. 6, but the steepness of the curve depends upon the speed of rotation of the magneto. The higher the speed is, the more rapid is the rise of current but, on the other hand, the shorter is the time during which the current is allowed to run. The result is that the energy per spark increases with the speed, but not so fast as we might expect. In fact, there may be an actual drop in energy per spark at very high speeds. Curve *M* of Fig. 7 shows approximately what happens. Obviously, neither of the curves of Fig. 7 represents ideal conditions. If the battery spark is strong enough at high speeds, it is too strong at low speeds. This is however highly desirable when trying to start a cold engine with a low battery. On the other hand, it is difficult to make the magneto spark strong enough at low engine speeds.

There are various things that can be done to improve either one of these conditions, perhaps especially the coil system. It is claimed by those who favor the coil that a very hot spark at very low speed is advantageous. I think every one will admit that this is true. The magneto men say they get plenty anyway, because magneto-equipped cars run successfully; but, under the very lowest speeds, certainly we would get more from the coil than we would from the magneto. On the other hand, the spark grows weaker as we reach the high speeds when using the coil. The coil-makers claim that they get all that is needed and that at high speed not so much energy is required to ignite the mixture successfully as at low speed. The mixture itself is likely to be much better and the compression is perhaps slightly better. This is certainly borne out to the extent that we do get successful ignition with the battery system at high speed, just as we get successful ignition at low speed with the magneto. The magneto manufacturers, on the other hand, claim that they have the hotter spark at high speed, which they argue is advantageous in that the mixture burns more rapidly and develops more engine-power. The battery-ignition man says that the spark-plug points burn away with the strong current. I shall not attempt to decide between the two. I have used both and have had trouble with both.

The much-debated question of whether a hotter spark gives more power in an engine has interested me and I

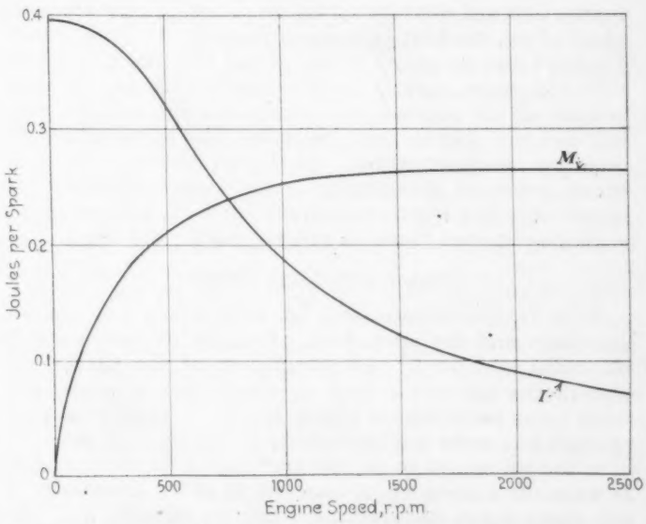

FIG. 7—CURVES SHOWING HOW THE ENERGY PER SPARK FROM AN INDUCTION COIL DECREASES WITH AN INCREASE IN THE ENGINE SPEED AND THE ENERGY IN A SPARK SUPPLIED BY A MAGNETO INCREASES

have experimented to a certain extent in regard to it. Suppose I have a sheet of paper that I want to burn. If I apply a small match to the corner of that paper it will burn. The question is, will it burn any faster if I use one of the old-fashioned big matches? I think it makes no particular difference, provided it burns at all. I admit that it is more likely to ignite from a big match if conditions are bad but, provided it does ignite and does burn, I cannot see that the size of the match is going to influence the speed with which the entire sheet of paper will be consumed, and that is what we are concerned with. I contend that the analogy is a good one. In a cylinder the flame travels with considerable velocity but it is a finite velocity just as there is a finite velocity of flame-travel for the sheet of paper. Provided the mixture burns at all, I cannot see that it makes much difference whether we have a large or a small spark. If we have the hot magneto-spark it might ignite the mixture when the coil spark would not ignite it at all; but, provided we do get an explosion, I believe that the speed of propagation will be about the same whether the spark is weak or strong.

I have been talking about the energy per spark; joules per spark means just the same thing. The joules per spark has been used by the Bureau of Standards in the comparison of coils, but I think it is not the best basis of comparison. The important thing is not the joules per spark, but the power. Work is, of course, power multiplied by time. I think it does not make much difference what happens at *c*, shown at the right in Fig. 5, but that it makes very much difference what happens at *b* when the spark first passes. The power is surprisingly great for a very short time. It is in the neighborhood of 50 watts, or about as much as a good-sized incandescent lamp takes; but it remains at this value only for an infinitesimal time such as perhaps 0.000001 sec. It raises the temperature of a small portion of the space to a high value for an exceedingly short interval of time. The power that is applied there is the thing that matters primarily. It is not power entirely either; it is power per cubic inch.

Of course it cannot be denied that, in the case of ordinary bodies, the temperature attained is a function of both the power expended and the time. In the case of a spark, however, the conditions are such that the heated matter can and doubtless does get away quickly from the place where the heat is being developed. In other words, I believe that the spark at the instant of formation is very thin and grows rapidly as the spark continues. A small volume of air between the points quickly becomes very hot and the volume then increases, the temperature remaining nearly constant. As I said before, I have no direct proof of this, except some visual inspection of sparks and the above considerations. If a direct proof could be obtained it would greatly clarify our ideas.

Short and Long Sparks

As a further illustration, let us compare two sparks, one short and the other long. Roughly, the gaps are in the ratio of 2 to 1. All dimensions of the sparks are also in the ratio of 2 to 1. I think that is practically what takes place with a longer spark. I am very sure it spreads out more and occupies more space. If we compare the volume of those two sparks, it will be as 1 to 8. If we make a thing twice as great in every dimension, it has eight times the volume. Let us assume that the power is in the ratio of 1 to 8, twice the voltage, four times the current. The power per cubic inch however is 1 to 1. The two sparks will therefore be approximately equally hot and the igniting power will be the same. It is true that the larger spark has a greater surface, but that would not make much difference in the rate of flame propagation, as I see it. It would help a little to spread it and the flame would not have to travel so far, but that is a very small matter which I think we can safely neglect. If this analysis is correct it indicates that the power per cubic inch is the proper criterion to use in determining the igniting power of a spark.

To illustrate further by referring again to the sheet of paper, I light it with a match. It does not matter how long the match is, provided the paper lights; the length of the match has absolutely no effect on the rate at which the flame will travel across the sheet of paper. Just so in the case of electric ignition. The follow-over part would have almost no effect because the mixture is already burning. Certainly, as soon as the mixture begins to burn, the heat liberated is much more than the spark could possibly give. It is conceivable that we might not get ignition at the very beginning, and that the follow-over part might possibly ignite it toward the end of the stroke. In that event the explosion would not be worth very much, because it would occur so late in the cycle of the engine.

I have performed one very simple experiment which indicated that, provided we get ignition at all, the power developed by the engine is independent of the strength of the spark. There are many variables in the usual engine-test. For example, we may make a test during a certain hour, and another test several hours later. Perhaps the barometric pressure is not then the same, or the mixture, or the spark pressure, or the degree of advance. A number of things may affect it. I think I left no chance for argument. I did not test as between magnetos and battery systems, but I tested as between hot sparks and weak sparks.

The test was made upon an engine equipped with battery ignition. The power output was measured by an electric dynamometer. A throw-over switch was arranged so that the number of cells used to furnish current to the coil could be changed instantly by throwing a switch. As first tried, the ignition voltage could be changed from 6 to 12, *thus increasing the energy per spark four times.* I got the engine running smoothly so that the balance-arm of the dynamometer did not move. I could throw the switch over one way and then the other; there was no difference; nothing happened. The dynamometer-beam never moved and the speed remained absolutely constant. I tried this with all sorts of combinations of cells. I did find that when the voltage became too low the engine began to miss, and of course I obtained more power on high voltage but, so long as the engine did not miss, I could not detect any difference. I tried making the mixture poorer and found that the engine would sometimes miss with the lower voltage whereas it would not miss with the higher voltage. But if everything was all right, there was absolutely no difference in power. I tried it at several speeds; running light and running loaded. The results were the same. I submit that this is a far better test than making a run with a battery and then making a run with a magneto at different times. There was absolutely no chance for change. The spark-advance was exactly the same and the conditions were absolutely identical. The above-mentioned test may be taken as an argument either for or against the magneto. It is wholly understandable that a magneto might be better than a coil system under certain circumstances. I can under-

stand that if the mixture were very poor and the engine running at high speed, the magneto might fire the charge when the coil would not, admitting that there is more energy in the spark. On the other hand, I can understand that at very low speed the coil might fire the charge when the magneto would not.

The amount of variation in the energy per spark that has been used in practice is rather astonishing. I have made a number of tests, and some results are shown in Fig. 8. Some years ago I had a car equipped with a well known magneto, the curve of which is shown at *a*. The curve of a typical battery system is reproduced at *b*. The output of the magneto seems absurdly low, yet I found no fault with the magneto. It ran all right. The engine could not be started on the magneto and a battery was necessary but, aside from that, the engine ran and operated all right with that exceedingly weak spark. The curve *d* shows typical results from a modern high-tension magneto. The spark has sufficient energy to ignite the mixture readily at cranking speeds. The curve *c* is that of a battery-ignition system giving more energy per spark than the coil of curve *b*. All these ignition systems worked fairly well, and there seemed to be enough energy with any of them. This is stated to point out that we can get fairly good ignition through a very wide range of energy per spark. Roughly, measured in thousandths of a joule, these ran from 25 as a minimum to about 325 as a maximum, a range of about 13 to 1, throughout which the operation was fairly satisfactory.

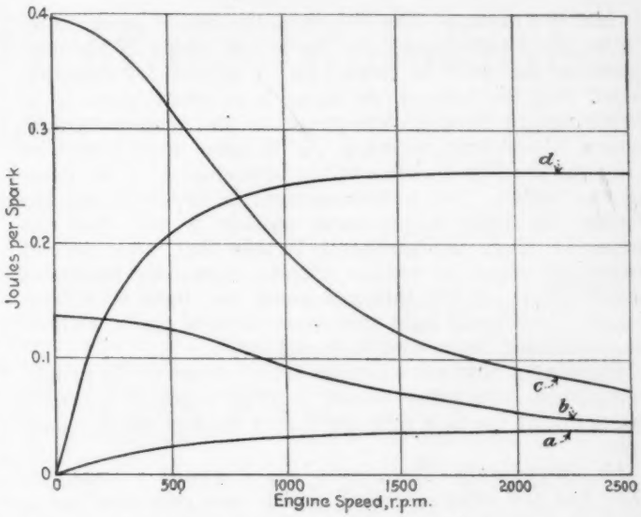

FIG. 8—CURVES SHOWING HOW CHANGES IN THE ENGINE SPEED PRODUCE VARIATIONS IN THE ENERGY PER SPARK SUPPLIED BY MAGNETO AND BATTERY IGNITION SYSTEMS

SPARK LAG

Another point worth noting is the lag in an ignition system. There was a large lag in the old-fashioned battery ignition in which a vibrator coil was used because, after the circuit was closed by the primary contact-maker, the current had to grow until enough current was obtained to magnetize the coil and pull the vibrator open. There was a definite time-interval before the vibrator would open and produce a spark, but there was not a definite angle. The angle was very small at low speed, and very large at high speed. Also, in the case of the so-called open-circuit system wherein a trigger is tripped and a contact piece is allowed to fly over, make contact and then spring back, we get the same sort of lag because there is a definite time-interval between the tripping of the trigger and the time when the spark is made. The lag is fairly large. It has to be taken care of by automatic advance or by allowing plenty of manual advance. With the ordinary coil of the so-called closed-circuit type the lag is very slight indeed. When the breaker-points start to open the current starts to decrease very fast. It does not come down in a straight line; the decrease is comparatively slow at first and then more rapid. At a certain point the rate of change becomes great enough to give sufficient voltage to make a spark jump across the gap of the spark-plug. The true time of lag is the time from *a* to *d*, at the right, in Fig. 5. The time-interval from *a* to *e* is ordinarily not over 0.0002 sec., so that the time from *a* to *d* would be in the neighborhood of 0.0001 sec. This gives a lag of 1 deg. with an engine operating at 3000 r.p.m. In the case of the magneto we have almost the same thing. The breaker opens in the same way and the current has to decrease in the primary of the armature before the spark passes in the secondary. However, there is this difference. In the magneto at high speed, due to the higher electromotive force, we do not have to drop so far on the curve before we get a sufficient rate of change to make the spark jump. The amount of advance required with the magneto is, therefore, slightly less than that with the battery system. The difference is very small. It amounts only to a fraction of a degree, assuming well designed apparatus.

THE DISCUSSION

FRED WEINBERG:—What is Professor Bailey's opinion of the type of magneto in which the magnetic flux is broken instead of the circuit in the primary? This type of magneto came out some 10 years ago and was made by a company in Massachusetts.

PROF. B. F. BAILEY:—I have heard of that, but I do not know enough about it to have formed an opinion.

MR. WEINBERG:—When you speak about magneto ignition, do you have primarily in mind the type ordinarily known today as the Bosch magneto?

PROFESSOR BAILEY:—Yes, the ordinary Bosch type.

MR. WEINBERG:—You did not include the so-called Witherbee type of magneto, which in my opinion forms a very strong bridge between magneto and battery ignition. It possesses the strength of battery ignition, together with the strength of magneto ignition, and eliminates the weakness of both.

T. J. LITLE, JR.:—Is it not a fact that as long as the temperature of the spark is well above the kindling point of the mixture to be fired, the ignition will be satisfactory, irrespective of whether the spark is produced from the magneto or the battery system?

PROFESSOR BAILEY:—I think that is true.

MR. LITLE:—That is the real situation. I thought possibly an analogy might exist in kindling a piece of paper, either with a match or an oxy-acetylene flame. The paper does not ignite better in the one case than in the other.

PROFESSOR BAILEY:—That is a very good illustration.

MR. WEINBERG:—There is no doubt that an oxy-acetylene flame would start the paper burning more quickly than a match would. It will take the oxy-acetylene flame considerably less time than the match to start the first part of the paper burning.

PROFESSOR BAILEY:—If my analysis of the two sparks is correct, one is not any hotter than another. It is simply bigger. Perhaps the analogy that I used between a small match and a large one more nearly fits the case.

MR. WEINBERG:—The length of the match seems to me to be of no consequence, so far as the length of time for burning the paper is concerned. I submit for consideration that the heat of the flame is of consequence as to bringing the fiber of the paper to the temperature at which it will start burning. If it takes some length of time for the fiber to come to the temperature of the flame of the match, then a time-element is involved and the hotter the flame is, the more quickly it will start the paper burning. An analogy is to take that same piece of paper and put it in sodium silicate, commonly known as water glass. I did this and could not light it with a match, but I could light that same piece of paper with an oxy-acetylene flame and it would burn.

PROFESSOR BAILEY:—I think that is a perfectly proper comparison. In other words, I think a hotter magneto spark might ignite a mixture that a weaker spark would not.

MR. WEINBERG:—Ten years ago I owned a runabout that had the old-time spark which was generated by a dry battery. Sometimes, when I had difficulty in starting, all that was actually necessary was to take my old battery cells out and put new ones in. When I took the spark-plug out and tried the spark, the spark was all right with the old cells. I never could make out why it was that it would not start with the old cells and would start with the new battery.

PROFESSOR BAILEY:—There is no question about that. When I first got a car with a magneto on it, I did not know what to do in case of such trouble. When the battery ignition stopped, after strengthening the battery it would be all right.

MR. LITLE:—A keg of gunpowder as compared to a cylinder in a gas engine would be the better analogy, rather than a piece of paper. The keg of gunpowder can be set off with a match as quickly as with the oxy-acetylene flame.

MR. WEINBERG:—I cannot agree, because gunpowder and dynamite are very unstable compounds and gas mixtures are rather stable. I prefer to take an intermediate step such as in the case of Thermit, which is a compound of aluminum powder and iron oxide. A quantity of Thermit cannot be started burning with a match. That is known. If a strip of magnesium is used as an intermediate agent, and ignited, the Thermit will start to burn from that. This is a point that is well worth investigation. Why does not the Thermit start burning with the match, when it will start with the piece of magnesium which has previously been ignited by that match? In other words, some intermediate agent is used for the purpose of bringing the ignition temperature up to that of the Thermit; the match is not hot enough to set the Thermit aglow. After the Thermit is once started burning it continues very rapidly; but that is after the magnesium has been used. That is in favor of my contention that the original ignition temperature is the prime factor of importance; that is, to bring the gas mixture to the temperature of the igniting medium. This Thermit analogy is submitted to illuminate that particular point.

PROFESSOR BAILEY:—We all recognize that it requires a certain amount of heat to start combustion, and the weak spark will not ignite a certain mixture when a hot spark will. I had one car which frequently would not start in the winter because the spark was too weak; when the engine was cranked by hand, thus relieving the battery of the starting current, it would start at once.

A MEMBER:—Suppose a spark in a cylinder 4 in. square and that the spark was 3 in. in diameter. That would ignite the mixture much more rapidly, no doubt. The final burning of the mixture would be much quicker than with a very small spark, but it would not be a desirable thing in ignition because it would approach detonation; in fact, it would be detonation. In other words, the spark would blast its way through the mixture that filled the entire cylinder. It would undoubtedly burn more rapidly, but it would not produce a gas; it would produce an explosion.

PROFESSOR BAILEY:—There is no doubt about that. If I light the sheet of paper on two corners, it will burn faster than if I light it on one corner only. Every one admits that more power is obtained from two sparks than from one. With four sparks I suppose it would be better.

C. F. JEFFRIES:—I think it will be found that the matter of gas turbulence is of more importance than the location of the spark-plug and the number of sparks per cylinder.

PROFESSOR BAILEY:—There is no doubt that is a big factor.

O. E. BARTHEL:—What is your opinion as to the desirability of having more sparks than one in igniting gas in a cylinder? I tried at one time to explain to a court the operation of a vibrating spark-plug, in relation to synchronism and the lag of the spark. We tried to use oscillograph photographs, but found them practically useless as we could not depend upon the operation. It was practically impossible to reproduce a photograph with the same coil and under the same conditions. We gave it up. Finally, we constructed an apparatus by mounting a paper disc and arranging it so that the spark would perforate very fine holes in the disc. This gave a correct curve of the lag of the spark at each setting. By taking the disc off the machine and holding it to the light, an exact view of every perforation was obtained. That was the way we explained to the court the operation of the spark coil, the lag of the spark and the synchronism.

PROFESSOR BAILEY:—There is no doubt either in theory or practice that more power is obtained with two spark-plugs than with one, especially in a very large cylinder. The size of the cylinder has much to do with it. A piece of paper lighted on two corners would not take so long to burn as if lit only on one corner. There would be two flames burning in two directions.

A MEMBER:—Might there not be some dead pockets?

PROFESSOR BAILEY:—I assume that neither spark-plug would be in dead gas. Assuming that both spark-plugs fire, it is borne out by tests that some increased power is obtained at high speeds. I have used the same device that Mr. Barthel mentioned for measuring lag. It worked very well indeed, and the effect was easy to see. I do not understand why he should have had so much trouble with the oscillograph.

MR. BARTHEL:—I went to the best engineers, trying to get a device that we could use in a demonstration to the court. They set up scientific apparatus but we found it was not practical. Some old-time coil-manufacturers finally set up the apparatus mentioned for me. It was better than anything I had used previously.

PROFESSOR BAILEY:—The oscillograph shows many things that this simple device would not, but for the one particular purpose stated the latter is very effective. I have used it to measure the lag of a single-spark system.

A MEMBER:—What effect has the width of the gap on the ignition?

(*Concluded on page* 607)

International Ball Bearing Standardization

By R. S. BURNETT[1]

STANDARDIZATION of ball bearings in America received its first impetus in 1911 when the Society adopted the three series of metric annular ball bearings known as the light, medium and heavy series. These bearings followed the German standard sizes in their main dimensions as at that time Germany was the principal manufacturer of ball bearings and many of them had been imported into the United States. It was recognized that standardization would have to follow closely the practice which had become well established in the American industries.

A few years later, bearings larger in diameter were produced in a considerable volume, and as there were differences in the dimensions used by a number of American and European ball bearing manufacturers, standards were formulated and adopted by the Society in 1919 whereby the then existing annular bearings of the light and medium series were extended.

Another type also, referred to as double-row bearings, had been developed by an American manufacturer, the bores and diameters of these following the existing metric standards to allow of interchangeability, but inch widths being selected. Eventually other manufacturers produced this type of bearing, and in 1920 the present S. A. E. Standard Annular Ball Bearings extra wide type were adopted to harmonize the somewhat different dimensions used by the several manufacturers. Foreign-made bearings, if there were any, were so few as to have no influence on the American standard.

During the same period bearings smaller than the existing standard sizes were coming into common use in the conventional annular ring and cage and the so called "magneto" types. The magneto type was made in Germany and imported into the United States for some time, and then made in this country for American consumption. The need being recognized, in 1919 the magneto type was standardized as the "Separable" or open type, and in 1920 the conventional small annular type was standardized as the extra small series.

Another series had been used previously to a very limited extent in applications requiring very light-weight bearings. There was some thought of standardizing this series, but as its use was so limited and its manufacture considerably more difficult and expensive, it was felt that a standard was not in order. It does not seem likely that it will be standardized.

Although standardization of ball bearings up to at least the beginning of the World War followed the German standards very closely, no particular attempt was made to establish international standards. In 1917 it became evident that some international standards, particularly as to tolerances, should be adopted, especially for use in aircraft. An international conference was arranged for and participated in principally by the United States, Great Britain, France and Italy, the Society sending regularly delegated representatives. As a result a few changes were made in the standard ball bearing tolerances which had been in use in the United States.

Since the close of the war, requests have been made principally by Switzerland, for international ball bearing standardization. These requests were addressed to the American Engineering Standards Committee, a body recently organized for the purpose of coordinating American engineering standards in general, and to provide a suitable channel through which international standardization can be conducted. This Committee referred the requests to the Society of Automotive Engineers and the American Society of Mechanical Engineers, which became sponsors for American standards for ball bearings, and were delegated to make recommendations for international standards.

A sectional committee, organized by these two societies, held a meeting in New York City in December, 1920, for the purpose of establishing a program. A subcommittee was appointed to secure as complete data as possible from foreign countries in which ball bearings are manufactured. These data were eventually received from Great Britain, Sweden and Germany, and transmitted to the sectional committee, and a meeting of the subcommittee was held in New York City in March for the purpose of formulating recommendations for consideration by the Sectional Committee. Information received from the British Engineering Standards Association had been reviewed and checked with the American standards, the practice found to be practically the same for corresponding series and types. No information was received from France. A letter from the Bureau des Normes Du VSM. (Vereins Schweizerischer Maschinenindustrieller), Baden, Switzerland, was to the effect that its work had come to a standstill, but that the committee expected to resume work soon. A letter from the Association Belge de Standardisation advised that standardization of ball bearings had not been taken up by that committee, as imported bearings, principally from Sweden, were used exclusively in Belgium. Dr. Jaro Tomaides, secretary of the Osterreichischer Normenausschuss Für Industrie und Gewerbe, wrote that a committee had been organized in Austria for the purpose of standardizing ball bearings, but that as there was only one ball bearing factory in Austria, it had been decided to accept the German standards.

The data received from Germany showed in detail the standards proposed there for extra light, light, medium and heavy single-row ball bearings of the conventional and of a self-aligning supplementary outer-ring type, as well as for double-row bearings of light, medium and heavy series.

The subcommittee referred to consisted of O. R. Wikander, chairman; G. R. Bott, F. W. Gurney, F. G. Hughes, and C. M. Manly, vice-chairman of the sectional committee. Discussion of the series proposed by the Germans indicated that there is very little use for an extra light series in American practice; such bearings as are used here are imported, principally from Sweden. They are considered very unsatisfactory to manufacture and limited to use in special types of apparatus and classes of service. The subcommittee felt that if an international standard for them should be proposed, the Swedish dimensions ought to be preferred, but that it should be the policy of the subcommittee at this time to not make any recommendation for standardization beyond the limits of American experience.

PROPOSED RECOMMENDATIONS

The proposed German standard light series includes the same small diameter bearings as the S. A. E. Standard except that there are no 6 or 8-mm. (0.237 or 0.315-in.) bore sizes in the German proposal; the German series from 9-mm. (0.354-in.) bore up to and including 110-mm. (4.331-in.) bore coincides with the S. A. E. Standard. From 120-mm. (4.724-in.) bore upward, however, the German bearings are lighter than the S. A. E. Standard Light Series

[1] M.S.A.E.—Standards manager, Society of Automotive Engineers, New York City, and secretary, American Engineering Standards Committee's sectional committee on ball bearings.

Extra Large Type, the dimensions of which are more in proportion to those bearings having bores up to and including 110-mm. (4.331-in.). The proposed German standards specify less width, depth and capacity than the S. A. E. Standard. It is believed that the larger American dimensions, particularly the greater widths, are preferable. With regard to bearings exceeding in size those of the S. A. E. Standard Light Series, Extra Large Type, the subcommittee felt that the present field of use for such bearings is so small and knowledge as to their best proportions so limited that standardization of them should not be considered now.

The S. A. E. Standard Medium Series and the proposed German standard for bearings with bores from 10-mm. (0.394-in.) up to and including 95-mm. (3.741-in.) agree. The S. A. E. Standard bearings having bores from 100 to 210-mm. (3.937 to 8.268-in.) inclusive, do not agree with the proposed German standard, but have dimensions more in proportion to the bearings with bores up to 95-mm. (3.741-in.). The proposed German standards specify less width, depth, and capacity than the S. A. E. Medium Series. The subcommittee believed that the larger American dimensions, particularly the greater widths, are preferable. The present field of use for bearings exceeding in size those of the S. A. E. Medium Series, Extra Large Type, is so small and knowledge as to their best proportions so limited that it was considered unwise to standardize them at present.

With regard to the Heavy Series, there seems to be no necessity for a standard extending beyond the present S. A. E. Standard list of sizes, as the capacity of such larger bearings would be so much greater than that of the shafts on which they would be mounted as to make them impracticable. The present S. A. E. Standard series is used largely in this country in sizes having bores up to and including 100-mm. (3.937-in.) and when adopted was practically the same as the previous German standard.

The S. A. E. Standard and the proposed German standard for bearings having bores of from 17 to and including 85-mm. (0.669 to 3.348-in.) agree. The field for bearings larger than the S. A. E. Standard Heavy Series being small and knowledge as to their best proportions limited, standardization of them is not deemed desirable.

In the S. A. E. Standard Light, Medium and Heavy Series of the Wide Type, the bores and outside diameters follow the S. A. E. Standard Annular Ball Bearings of the Light, Medium and Heavy Series, the differences being in the widths. The Extra Wide Type, originated in America, is intended to take radial and considerably greater thrust loads than the single-row annular bearings. This series has become so thoroughly established that it is felt that any changes therein would not be practical.

The standard sizes Nos. 200 to 203 inclusive and Nos. 300 to 302 inclusive were not included in the recommendation of the subcommittee, serious doubt having arisen in the mind of the American users and manufacturers as to the desirability of increasing the width of these particular bearings. The standards which have been proposed by the German Committee for these wide bearings, are nearly all narrower than has been found satisfactory in American practice.

In the German proposals the corner radii advance by smaller increments than in the S. A. E. Standard and in many instances fractional millimeter radii are specified. The careful consideration given to corner radii when the ball-bearing standards were adopted and revised by the Society seems to warrant proposing the S. A. E. practice for the international standardization. Particular attention was called by the subcommittee to the fact that the minimum corner radii in the S. A. E. Standard denote the maximum fillets of shafts or housings that the bearings will clear, and that if the minimum corner radii are made smaller than specified in the S. A. E. Standards, bearings so dimensioned may not be interchangeable with the American standard bearings, due to possible fillet and bearings interferences. It is believed that larger fillets than are current in American practice are not required for strength of shafts and any increase in fillets and corresponding increase in corner radii of bearings, would reduce the actual pressure or seating area of the bearings, and perhaps entail an otherwise unnecessary increase in shoulder-height and raw-stock diameter of shafts.

The meeting of the Sectional Committee on Ball Bearings held in March was attended by the following members: Chairman W. R. Strickland, Vice-Chairman C. M. Manly, G. R. Bott, G. E. Greenleaf, F. W. Gurney, F. G. Hughes, G. E. Hulse, W. P. Kennedy, E. H. Lockwood, E. Nides, O. R. Wikander and Secretary R. S. Burnett. Dr. P. G. Agnew and T. C. D. Crow also were present. The absent members of the Sectional Committee were C. H. Day and C. Mills. Mr. Wikander, chairman of the subcommittee, presented its recommendations. The gradual development and adoption of existing foreign and American standards were reviewed and the basic principles upon which international standardization should be founded, and the influence upon international standards of present and probable future industrial conditions, discussed at considerable length. The unanimous decision was that inasmuch as the present S. A. E. Standards have become thoroughly established in American practice and to a large extent in Canada, Australia, India, China, Japan and Europe, any attempt to change them for the sake of international standardization would be unsuccessful and result in "paper" standards only, particularly in the United States. In view of the fact that the greatest volume of ball bearings is manufactured at present in the United States and used in American apparatus, and that the present standards were originally based upon the previous prevailing German standards, the sectional committee saw no reason for making changes in these standards at this time, the true value of standards depending obviously upon what is reduced to actual practice. Any attempt to change present practice would cause confusion.

Proposed International Ball Bearing Standards

After consideration of the report of the subcommittee and of what should be recommended for international standardization of ball bearings, the sectional committee voted unanimously to report to the American Engineering Standards Committee that

> After considering the matter of ball-bearing standards, it is the sense of the sectional committee that the American Engineering Standards Committee should recommend as international standards the existing S. A. E. Standards for Annular Ball Bearings, shown in the S. A. E. Handbook (revised edition), Vol. 1, pages C25 to C33 inclusive, with the exception of the Extra Wide Type, sizes Nos. 200 to 203 inclusive of the Light Series, and Nos. 300 to 302 inclusive of the Medium Series, shown on page C31, which sizes are under reconsideration regarding widths.

In view of the fact that the German national standardizing committee was planning to meet early in April for the purpose of acting on the proposed German ball bearings standards, the Sectional Committee on Ball Bearings recommended that the American Engineering Standards Committee send a cable to the German committee stating that the existing S. A. E. Ball Bearing Standards, with the exceptions referred to in the foregoing recommendation, are proposed for adoption as international standards.

It was further suggested that copies of the complete recommendations of the Sectional Committee be sent to the national standardizing committees of other countries with which the American Engineering Standards Committee has communicated with regard to standardization of ball bearings, and that Dr. Agnew, secretary of the American Engineering Standards Committee, confer with the chairmen of the foreign ball bearings standardizing committees in those countries whom he will see during his trip to Europe in April and May.

The work of the Society and the Sectional Committee on Ball Bearings is the most important concerted action that has been taken toward the establishment of unified ball bearing standards throughout the world.

Turbulence

By H. L. HORNING[1]

SEMI-ANNUAL MEETING PAPER *Illustrated with* DRAWINGS

GREAT interest has been shown in turbulence since the subject was revived a year ago. This paper is a collection of notes gathered from investigation of the subject in the literature on the development of internal-combustion engines and memoranda set down during a long series of tests. The paper includes a discussion of the physical and chemical aspects of the case and sets forth a working theory which has proved of value. Several methods of measuring turbulence are set forth.

HISTORICAL

Turbulence is one of the simplest things in ordinary life made mysterious by a name and lack of explanation. Turbulence is merely mixing to hasten the contact of two substances in a semi-liquid, liquid or gaseous state. Stirring of coffee to dissolve sugar is the most common daily use of turbulence. The whole art of ventilation is turbulence in a commercial form. The paddles on an ice-cream freezer are for the purpose of producing turbulence. German chemists dignified turbulence by a name. Le Chatalier and Mallard noted its effect in their classic investigation on flame propagation. Various other investigators have noted the increase in flame propagation due to turbulence. Wheeler and Mason note a doubled flame-velocity in a tube of 0.8-in. diameter between a quiescent mixture and one traveling at a rate of 9 in. per sec. along the same tube.

Prof. Bertram Hopkinson noted an increase in flame velocity in a closed vessel fitted with a fan. With a 9 to 1 air-gas mixture it took 0.13 sec. to attain the maximum pressure. With the fan running at 2000 r.p.m. the mixture came to the maximum pressure in 0.03 sec. At 4500 r.p.m. it took the mixture 0.02 sec. to attain maximum pressure. Sir Dugald Clerk in the same year, 1912, in which the Hopkinson experiments with closed vessels were performed, showed that where a 9 to 1 mixture was exploded on first compression the mixture attained a maximum pressure in 0.037 and 0.033 sec. in two separate explosions. When the mixture was ignited after it had been compressed three times, the turbulence being thus allowed to die down, the maximum pressure was attained in 0.092 and 0.078 sec. respectively; the rise in pressure in both cases being 2.5 times as fast with a turbulent flame. Clerk calls attention to the fact that the difference in the speed of pressure development between the first and second explosions is due to the more favorable location of the ignition, an important fact dealt with at length later in the paper. To Sir Dugald Clerk is probably due the credit of first recognizing that turbulence produces high indicated thermal efficiency at all speeds. Harry Ricardo has studied turbulence in later years and determined that with normal timing gas velocities through the intake-valves of from 130 to 160 ft. per sec. give the highest brake mean effective pressure, whereas velocities of from 160 to 180 ft. give the maximum brake thermal efficiency and velocities of from 180 to 200 ft. give the maximum indicated mean effective pressure. Ricardo has also made a study of combustion-chamber shapes and arrived at efficient shapes for various types of combustion-chamber. In England, France, Germany, Italy and the United States there has no doubt been a thorough study of turbulence in engines as there is a general use of gas velocities between fairly close limits in aeronautical engines produced in those countries. In this country Woodward, Lewis and Canby of E. I. Du Pont de Nemours & Co. have set forth their investigations in a very able paper which was recently published in THE JOURNAL.[2] The Bureau of Standards has done some good work in this connection but has not published its findings as yet. P. S. Tice has done some very creditable work in the investigation of turbulence by taking photographs of mixture-currents in glass models. This was described in THE JOURNAL.[3] It is pleasing to know that these photographs confirm the general course of the currents in cylinders shown.

Turbulence is any circulation in the mixture by which rapid mixing of the contents is effected during explosion. All forms of turbulence are of value in aiding orderly combustion. General currents are the most effective in distributing the flame and are the most easily maintained and economically produced. Eddy currents are less effective. These currents will be discussed in the section of this paper on methods of producing turbulence.

EFFECT OF TURBULENCE ON FLAME PROPAGATION

An examination of a large number of flame photographs indicates that there are four possible phases in the velocities of the flame in a tube of uniform cross-section, not all of which are apparent but which may be approximated in nearly all mixtures. The four phases through which the velocities pass are as follows: The flame traveling from *I* to *A*, Fig. 1, accelerates; and this phase is known as the phase of first acceleration. As the flame travels from *A* to *B*, it takes a uniform velocity; this phase is known as "the first phase of uniform velocity." As the flame travels from *B* to *C* it passes through a second acceleration, and is so known. The flame then travels from *C* to *D* attaining a high uniform velocity, and continues at this rate, which is known as "detonation." The use of a tube in the study of flame is merely a device for drawing out the process of ignition, and for developing these four phases of flame velocity. The tube tends to stabilize the conditions of quiescence and remove such artificial physical factors as stimulate the rate of reaction outside the kinetic energy of its constituents and outside temperature and pressure. Since the flame travels into an entirely fresh mixture undiluted by products of combustion, it increases in velocity rapidly due to increasing temperature and pressure, restrained only by constant area of the flame-crest, the chemical stability of the fuel and dissociation of the products of combustion.

[1] M.S.A.E.—Secretary and general manager, Waukesha Motor Co., Waukesha, Wis.

[2] See THE JOURNAL, March, 1921, p. 209.

[3] See THE JOURNAL, March, 1921, p. 282.

A tube has a limiting influence on the volume rate at which the mixture is consumed. In a tube the only way large volumes of mixture can be consumed in a unit time is by increasing the velocity of the flame. Where mixtures are contained in more compact chambers and the flame initiated at one point, the flame may travel out into the quiescent mixtures, which may happen in tubes of large diameter, and then recede or stop only to go forward again, causing a pulsating flame. All these manifestations seem to be a combination of increasing pressures, temperatures and the effects of the column-lengths and elasticity of gases. When the flame is started, a sound-wave is set up and travels to the nearest wall, reflects and passes through the mixture, producing visible effects in speeding up and slowing down the combustion.

For the practical man we may set forth some facts which seem fairly well established. The region *A-B*, Fig. 1, represents a condition of combustion which if it were possible to attain with homogeneity throughout the mixture would produce the highest thermal efficiency. The successive stages of *B-C* represent an increasing presence of too rapid combustion of some of the contents, with the resultant incandescence of solid carbon particles. These particles represent an increasing loss by direct radiation and no doubt this radiant heat affects the regions of unburned mixtures and accounts for a rapidly increasing reaction in these regions of flame. *B* is a point of low dissociation and may therefore symbolize the best compromise in practice between the controlling chemical and physical factors contributing to the highest thermal efficiency.

Phase *I-A* may be considered as the typical combustion had with lean mixtures and at low loads, and from a thermodynamic standpoint is characterized by a smooth sweet-running engine. Phase *A-B* represents the combustion of the most economical mixtures at loads at and under those giving maximum economy, provided there is no marked or incipient auto-ignition. This is at nearly full-load performance and with lean mixture of low-compression engines down to normal running. This phase is not characterized by a roughness in performance of the engine. Phase *B-C* is characteristic of the flame in an engine having a compression just low enough to avoid detonation at the most economical mixture, but running with a richer mixture. This may also be representative of an engine running when the compression-ratio is somewhat too high for available fuels. It is typical of the large class of cars built in the past for more volatile fuel. The condition is shown when running at full throttle either accelerating or at full load and particularly at slow speed. The action corresponding with this is a very rough performance and the effects can be easily felt as well as heard. Phase *C-D* is representative of very rough performance of an engine in which the compression-ratio is too high for the available fuels, the engine running at full load with a perfect mixture. The roughness is greatest at the speed of maximum torque, that is at relatively low speed.

The first phase is one in which the flame is blue. The second phase increases the intensity of color, which sometimes approaches green, indicating the very best and most efficient type of combustion. The third phase is one in which a yellow color is emitted from the flame, and the fourth phase is one in which the flame has a brilliant white appearance.

Inasmuch as the efficiency of combustion is represented by the velocities not exceeding *B*, the problem of combustion in internal-combustion engines resolves itself down to a resort to other means of increasing volume consumption than by flame velocity. The theory used and developed is the theory of maximum areas. This involves the simple geometrical fact that a volume is generated by an area sweeping through a given distance. In other words, in a quiescent mixture the most effective way of consuming the greatest volume of mixture in the shortest space of time is to provide a shape of chamber in which the flame surface or crest can spread out, developing at each successive advance an increasing area of contact with the unburned mixture.

In Fig. 2 at the upper left corner there is shown a conical-shaped chamber in which the lines drawn are the successive positions of the flame-crest at uniform intervals of time. In this form of chamber the area of the crest decreases very rapidly. In the lower left diagram, Fig. 2, is shown a conical chamber with ignition starting at *I*; the lines represent the advance of the flame in equal divisions of time. This form of chamber favors the development of an increasing area of the crest with each successive advance of the flame. It can be shown that the volume consumed in this form increases as the cube of the distance from the firing-point and since the distance traveled may vary in some mixtures roughly as the cube of the time, it is evident that great volumes can be consumed in very short intervals of time. This high rate of volume consumption is based on the assumption that the flame is traveling into unburned mixtures and does not take dissociation or dilution into consideration. If we make a figure of two cones, as in the upper right diagram of Fig. 2, starting the ignition at the point *I*, the flame will then travel out as shown and we will consume twice the volume of mixture in the same length of time.

Referring to the lower right-hand diagram, if we generate a sphere with a great number of cones, igniting the mixture at *I* at the center, we will consume the greatest possible volume in a given time with one ignition point. It has been found by Hopkinson in tests of explosive mixtures in vessels having approximately the form of a sphere that the rapidity of rise in pressure is maximum when the mixture is fired at the center, and minimum when the mixture is fired at one side. All these considerations have been based on a *quiescent* mixture. Many points of ignition afford means whereby great volumes of explosive mixture can be fired without reaching high unit-velocities of the flame at any region of the mixture. If we produce rapid enough circulation of the gases, that is sufficient turbulence, it is possible by igniting the gases at the point of greatest rapidity of movement to approach approximately the effect of a multitude of ignition points and, with a large number of "ignition points" so distributed throughout the mixture, to initiate numerous spheres of flame and therefore an infinite number of small velocities and rapidly increasing flame areas, and so consume the maximum volume of mixture in a unit of time without approaching the flame velocities of detonation. There are other considerations such as the area-to-volume ratio and the fact that spark-plugs have to be located at the outside of a sphere, considered as a possible combustion-chamber, but these need not be discussed here other than to state that, there being a cool layer of gas on the walls of the combustion-chamber, turbulence insures the consumption of a larger volume of gas in a given time by driving this cool surface gas off into the flame, replacing it with the products of combustion. In a sphere the volume of this layer of cool gas is at a minimum, while in side-pocket engines it is relatively greater and turbulence is of correspondingly greater importance.

Turbulence is merely a physical assistance to the process of chemical reaction by aiding the kinetic tendencies of one species of molecules to make contact with those other species with which they must unite under the conditions of temperature and pressure in the cylinder. The process of chemical reaction, of which combustion is one type, is a surface phenomenon. The modern conception of the constitution of the atom is that the outside layer of electrons is the one which gives the atom or molecule its chemical properties. Therefore, when we attain the maximum of flame-swept volume by adopting those shapes of combustion-chamber which will allow the most rapid increase of flame-crest area of quiescent or turbulent mixtures, we follow the most fundamental law of chemistry, that is, develop the maximum contact surface for reaction. In very slow combustions the reaction of hydrocarbons is in very many steps. As the reaction increases in rapidity, the chemical stages through which a unit-volume of mixture passes become more direct and it seems from all known considerations that the most thorough and best controlled combustions are those in which the combustion-chamber may be considered to be filled with a mixture comprising a large number of small volumes in which the initial and end stages of combustion are occurring at one time intermingled with the products of combustion and their dissociations. There should, therefore, be a general homogeneity throughout the mixture in temperature, pressure, chemical species and state of equilibrium, rather than a progressive reaction from one part of the mixture to the other. Turbulence tends toward the ideal condition in which the various reactions going on in any small section at any one time are somewhat typical of those in a section of similar size in any part of the mixture. This is the very antithesis of the conditions in a tube. On the other hand, turbulence can be controlled so as to cause a useful segregation in the mixture and it is thus possible to fire the mixture at its richest section while some parts may resist ignition. By this means it is possible to attain exceptional economies.

There are three surfaces in any combustion-chamber which inherently have a temperature above the average; the center of the piston, the center of the exhaust-valves and various points in the spark-plug. Turbulence tends to prevent the layers of gases over these points from reaching the point of auto-ignition. Where these layers occur in shallow pockets there is less opportunity for turbulence to keep the gases moving and the high temperature of the mixture at these sections must be kept in mind in locating spark points, as it has been proved by many investigators that the spark-plug should be placed in such a position as to ignite the hot portion of the mixture during the early stages of combustion when it is relatively cool rather than allow a flame traveling some distance to set this hot portion off by auto-ignition toward the latter part of combustion when temperatures and pressures are high and the maximum of radiant heat is flooding the combustion-chamber. When three high-temperature spots and a pocket claim the location of the spark-plug, it is necessary to compromise, giving preference to that locality which will set off the hot sections in a pocket first and then the mixtures of lower temperature. Generally speaking, after the pocket is taken care of, the spark-plug should be as near as possible to the greatest turbulence and the center of gravity of the mixture.

There are three spots where a spark-plug should not be placed; at any point remote from a pocket; at any point remote from a hot surface; at a point where it will be

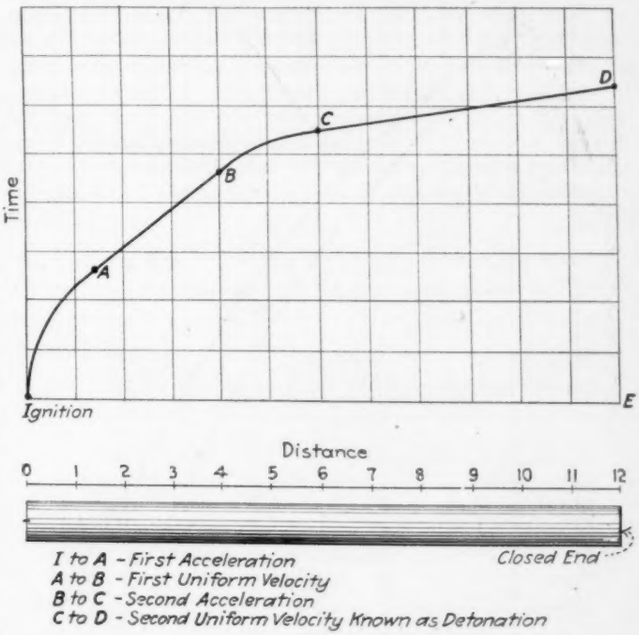

FIG. 1—DIAGRAM SHOWING THE VARIOUS STAGES IN FLAME PROPAGATION IN A TUBE HAVING A CLOSED END

washed by the exhaust and the pumping action of the rings.

In all natural processes the flow of energy is from the high to the lower levels. In a cylinder between the time of the spark and that of highest pressure several changes are going on. There is the drop of chemical energy in the form of active fuel and oxygen to the lower level of the products of combustion. There is the liberation of energy in the form of heat, light and electric energy during this process.

The undesirable characteristics of knock seem to come about because of vast differences in condition between relatively large masses of reacting gases in different parts of the cylinder. The process of combustion of the first portion of mixture is orderly because the layers of fresh gases are not close to their self-ignition temperature. There are great differences of temperature at any

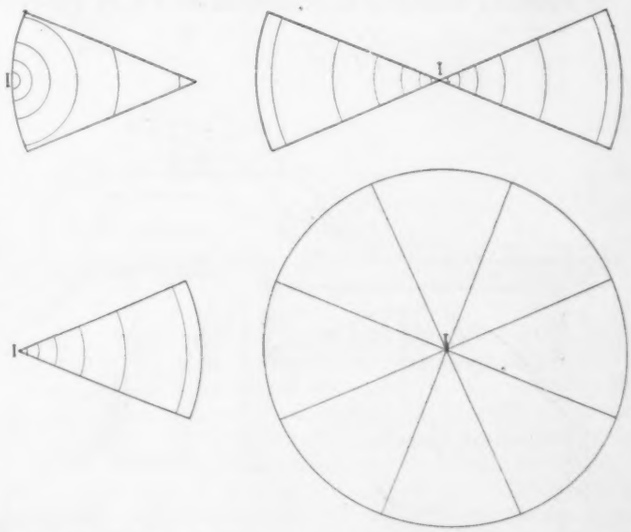

FIG. 2—DIAGRAM SHOWING THE INCREASE IN THE AREA OF THE FLAME-CREST IN DIFFERENT FORMS OF COMBUSTION-CHAMBER

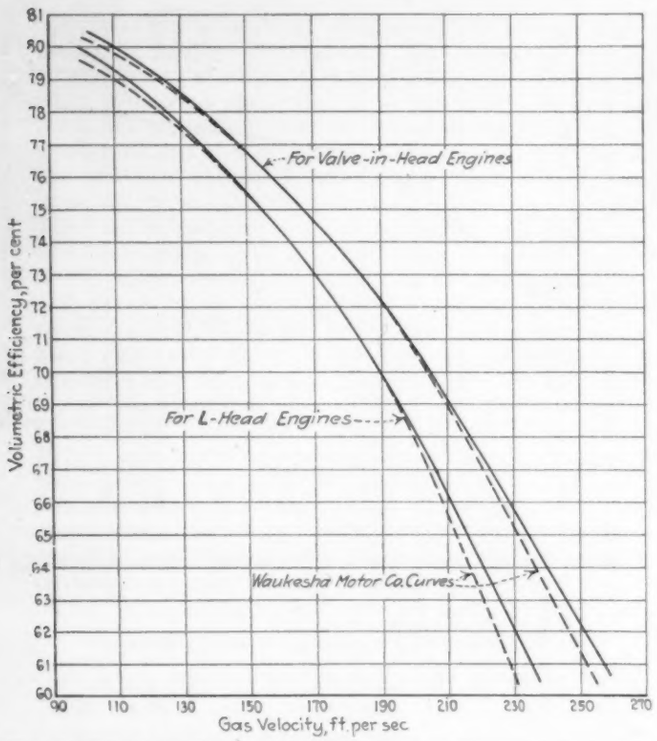

FIG. 3—CURVES OF INTAKE-GAS VELOCITY FOR VALVE-IN-HEAD AND L-HEAD ENGINES

instant during the combustion period. There exist great differences between the chemical species in different parts of the combustion-chamber during the combustion period. While rapidity of combustion is a desirable feature it is not desirable if it is attained by the precipitous processes represented by velocities at *B-C* and *C-D*, Fig. 1. The distinction to be kept in mind is large volumes consumed in unit time with limiting reaction velocities.

TWO METHODS OF PRODUCING TURBULENCE

Turbulence is produced by two fundamental methods based on the means by which the circulation is initiated. The first and most common method is by means of the intake-gas velocities. There is a fundamental defect in this method inasmuch as it depends on a high gas-velocity, which means relatively low volumetric-efficiency. Ricardo has worked out two curves of intake gas-velocity and volumetric efficiency (See Fig. 3). The lower curve is for L-head engines and the upper curve for valve-in-head engines. Our own curves are shown in dotted lines. It is common practice in England to treat the area of a valve as clear diameter x π x lift. It can be shown that this gives, with the average-shaped cam, an average

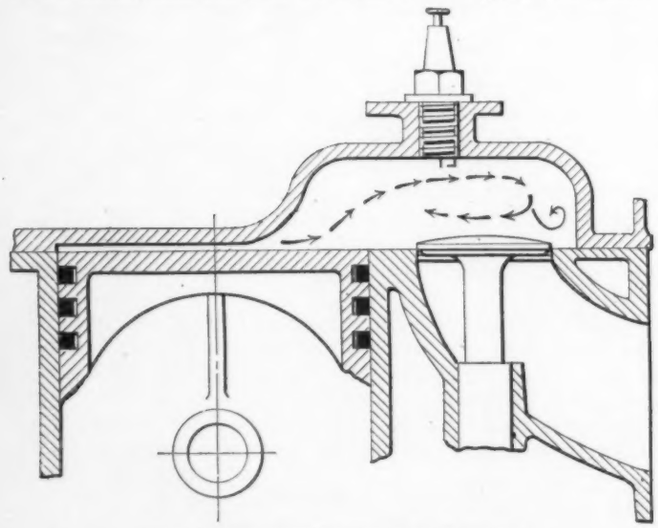

FIG. 4—CYLINDER DESIGNED BY RICARDO

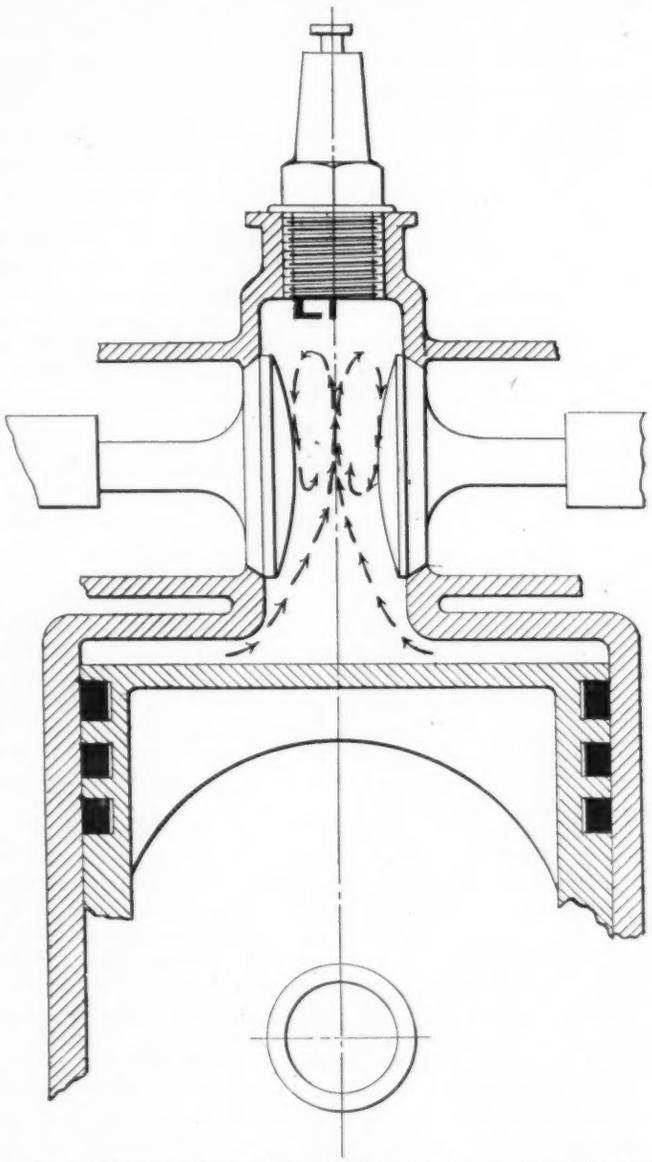

FIG. 5—DESIGN WHICH USED KEROSENE AS FUEL IN THE RICARDO TANK ENGINE

velocity value of practical form for use in calculating. We use this method in our work and all the curves shown are based on this understanding of gas velocity. It is obvious by this that since the maximum brake mean effective pressure lies between gas velocities of 130 and 160 lb., the best volumetric efficiencies for maximum brake mean effective pressure lie between 74.5 and 77.5 per cent for L-head engines and 75.5 and 79.0 per cent for valve-in-head engines. Since the highest indicated mean effective pressures lie between 180 and 200 lb., it is obvious the highest indicated mean effective pressures lie between 68.0 and 71.5 per cent volumetric efficiency for

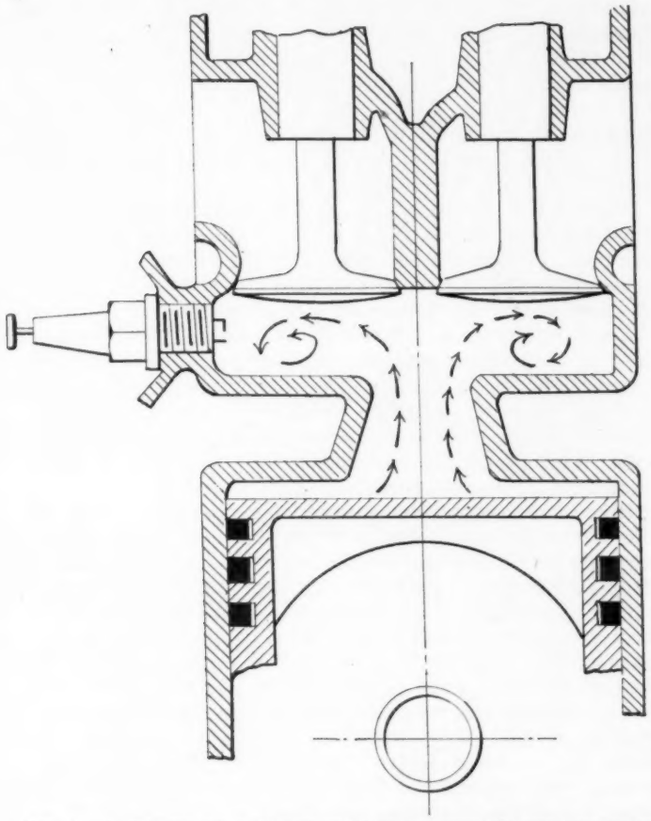

FIG. 6—A DESIGN OF A VALVE-IN-HEAD ENGINE WHICH PRODUCES TURBULENCE BY FORCING THE CONTENTS OF THE CYLINDER AT A HIGH VELOCITY THROUGH A VENTURI OF SMALL AREA INTO THE COMBUSTION-CHAMBER ON THE COMPRESSION STROKE

L-head engines and 70.5 and 73.5 for valve-in-head. The highest brake thermal efficiency comes close to and slightly above the velocities of maximum brake mean effective pressures.

Gas passages in the cylinder, which means the chamber shape, have a great influence on volumetric efficiency; so the figures above are a guide to diagnosis in experimental development. We have found, of course, that the velocities through the venturi in the carbureter have an important effect on indicated thermal efficiency and indicated mean effective pressure and they run from 420 to 520 ft. per sec. in Zenith and in Stromberg carbureters for maximum indicated mean effective pressure. So many factors enter into this that these results can be considered only as representing the performance of a fuel more volatile than commonly found and with a good aromatic content. With heavier fuels higher velocities give better results, particularly in the manifolds and chokes.

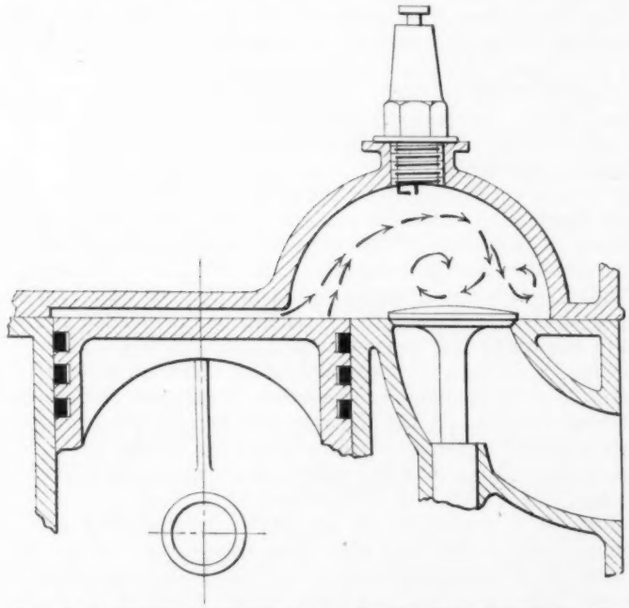

FIG. 7—ANOTHER DEVELOPMENT TO SECURE TURBULENCE IN THE VALVE-IN-HEAD ENGINE

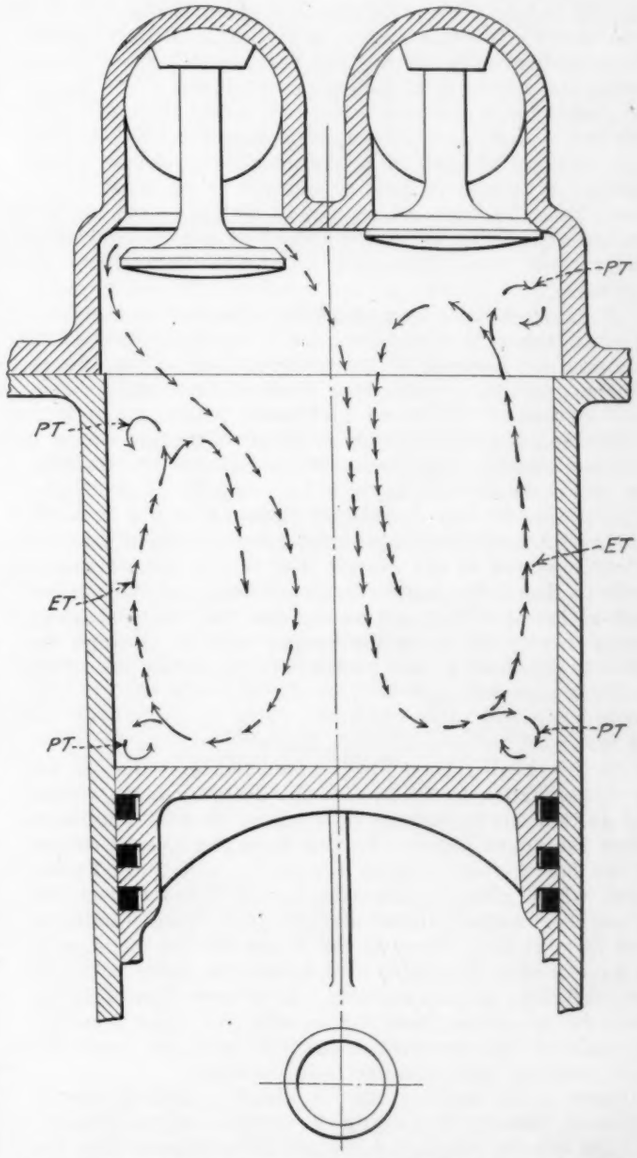

FIG. 8—DIAGRAMMATIC VIEW OF THE CYLINDER OF AN OVERHEAD-VALVE ENGINE SHOWING THE PATH OF THE MAJOR CURRENTS IN THE GAS

Turbulence is produced primarily by the velocity of flow past the intake-valves during the suction stroke of the engine, and secondarily through the subsequent flow of the gases on the compression stroke. The flow through the intake-valve is at high velocity but discharging into a relatively large chamber the velocity tends to drop

abruptly due to the volume of the space and particularly to its shape. The turbulence which may be developed during the suction stroke is particularly susceptible to the dampening influences that generally exist during the compression stroke when the gas is being forced into a smaller space and at this period the persistency of turbulence is particularly subject to the influence of combustion-chamber shape. Whatever the natural direction of the gases, the shape of the head and all parts of the chamber should be such as to introduce no irregularities into the path. The flow during entry into the cylinder should induce a high velocity and symmetrical course of the gases after the valve is closed, this path merely lengthening or shortening, but keeping its general course when the piston is at its various positions. The energy available for turbulence is limited; hence the most regular and undisturbed paths tend to conserve the velocities. The moment of ignition is the moment of utmost importance. Whatever is done to produce or maintain turbulence must be done entirely in reference to the moment of ignition, for it is the turbulence at this instant which determines the distribution of flame throughout the cylinder.

In engines depending on intake gas-velocities for turbulence there is always a restricting influence in the compromise between high turbulence and volumetric efficiency, and this points to a more effective and convenient method of producing turbulence which will now be described. In Fig. 4 will be noted a design which is due to Ricardo. This design was developed by him after he had observed the very effective way in which the design shown in Fig. 5 handled kerosene in his tank engines with a relatively high compression without a knock. Ricardo stated to the author that it was almost impossible to make this engine knock on kerosene at compression-ratios of 4.75-1. It is obvious that in this design turbulence is set up at the proper moment through the velocity produced by the piston forcing almost the entire cylinder contents past the opening between the cylinder proper and the valve chamber. This opening need not be restricted to produce high initial velocities, for there is no intervening time for the turbulence to die out before the spark passes; in fact the design can be worked out so that the turbulence is reaching its very maximum when the spark passes. In this form the great problem is the flat section between the piston and the cylinder-head, which gives opportunity for the flame to run and knock from auto-ignition. From a turbulence standpoint this form is very effective and it can also be made so as to have a very favorable area-to-volume ratio, which is the coefficient of compactness. It is very favorable because of its compactness for an effective spark location. By making the combustion-chamber a hemisphere the most compact form possible is introduced.

There is still another way in which turbulence can be produced, namely, by forcing the contents of the cylinder at high velocity through a venturi of small area into the combustion-chamber on the compression stroke. Fig. 6 illustrates this for a valve-in-head engine and Fig. 4 for an L-head engine. Fig. 7 illustrates still another development. The fundamental difference between these methods and those met with in conventional systems is, first, that compression backed up by the piston furnishes a much more positive means for causing turbulence than the atmospheric pressure during the suction stroke and, second, gives an opportunity for producing a much more general movement of the gases and, third, turbulence occurs immediately before and during ignition, thus obviating its dying out. The defect of these systems is the increase in combustion-chamber area and the introduction of thin layers of gas at some points. So far as the main chamber is concerned there can be no detonation, but unless highly stable fuel is used there will be detonation in the shallow sections over the pistons. The main combustion-chambers of these forms have a relatively small area-to-volume ratio.

Turbulence produced by piston compressions is the most effective known for a given speed of engine. The gas must go through two passages, the valves and turbulence orifice, on the suction stroke; therefore, large areas at these points are advisable and permissible to sustain volumetric efficiency. However, because of the effectiveness of the method and the simplicity of flow and high velocities of the mixture at the moment of ignition, it is doubtful whether such high velocities of mixture through the turbulence orifice are needed as have proved necessary when producing turbulence by intake-gas velocity in normal types of combustion-chamber.

Figs. 8, 9 and 10 are marked *ET* to show points of effective turbulence. The paths shown indicate the major currents in the gas and should be provided for by design. They represent the greatest velocities and should involve a high percentage of the total mass of the mixture. The most effective turbulences are those involving the entire mass of the mixture in a general movement of highest velocity and along one simple course. This involves less loss in velocity and minimizes the eddies which generally may be considered as parasitic turbulence, marked *PT*. Since these eddies derive their energy from the main stream, they impede it. They are also of lower order of velocity and therefore less effective.

In engines of a design depending on intake-gas velocities for turbulence the proper combustion-chamber is that which follows most closely the lines of flow of the mixture. Such a form is illustrated in Fig. 11. Another form is shown in Fig. 12 in which the path of turbulence is indicated.

Characteristic Turbulence in Typical Cylinders

Fig. 8 shows diagrammatically the general currents in an overhead-valve engine of well known design. It is obvious that when the contents are compressed the contending currents will tend to wipe themselves out; this is the reason why overhead-valve engines take higher gas velocities to attain maximum brake mean effective pressure, brake thermal efficiency and indicated mean effective pressure. This type is the least effective from a turbulence standpoint. Fig. 9 shows an ordinary flat type of L combustion-chamber, the eddy currents illustrating how ineffective it will be and the large area-volume ratio makes it ineffective. This type will have low mean effective pressure and thermal efficiency. Fig. 10 is the usual T-head type which must be run at high speed with spark-plug located as shown to get sufficient turbulence for a high mean effective pressure and thermal efficiency.

Fig. 11 shows a form of combustion-chamber which Ricardo claims to have used on his design of the Mark Webber engine. While the reported results are remarkable we have never attained satisfactory results with the spark-plug placed over the piston as shown in his reports. In fact, we always had very severe knocking.

Fig. 12 is a type which has shown good results when the piston and head are like those illustrated in Fig. 11, but as shown here usually requires high speed to give sufficient turbulence for maximum mean effective pressure and thermal efficiency.

Fig. 4, Ricardo L-head type, gives a high turbulence and excellent brake mean effective pressure and thermal efficiency at all speeds and with a very small spark-advance.

Fig. 7, the Tyler type, in which the combustion-chamber is hemispherical in form, gives excellent results.

Fig. 5, Duesenberg type, is the same as that used in Ricardo's tank engine and the Bugatti aeronautic engine. It is very fine from the turbulence standpoint, gives high mean effective pressure and economy at all speeds and takes a relatively small spark-advance.

Fig. 6 shows a turbulent overhead-valve type in which the piston forces the cylinder contents into the combustion-chamber at high speed and thus makes it one of the best types from a turbulence standpoint.

Methods for Measuring Turbulence

The indicated mean effective pressure may be analyzed as consisting of the indicated mean effective pressure that would be attained if all the fuel-energy were available on the piston without loss multiplied by several efficiencies.

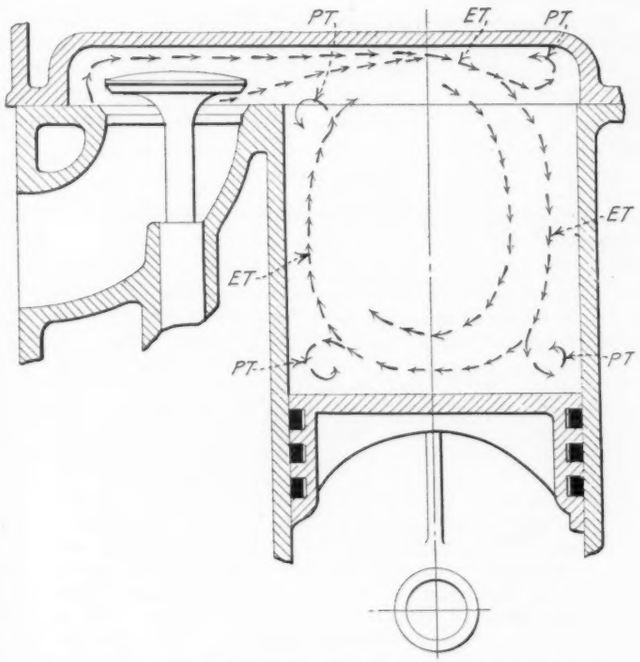

Fig. 9—An Ordinary Type of L-Head Combustion-Chamber

$$IMEP = Ae \times Ce \times Ve \times (D \times 12)$$

where

$IMEP$ = Indicated mean effective pressure
Ae = Air-cycle efficiency
Ce = Relative efficiency
Ve = Volumetric efficiency measured in pounds of air at standard temperature and pressure
D = Foot-pounds of energy per cubic inch of mixture
ITe = Indicated thermal efficiency or $Ae \times Ce$

The air-cycle efficiency values given in Fig. 13 are calculated from the formula $A_e = 1 - (1/r)^{0.4}$ where r is the ratio of compression. At a constant speed and with all the other factors such as the air-cycle and volumetric efficiencies and the energy content constant it is obvious that the relative efficiency which is obtained by dividing the indicated thermal efficiency by the air-cycle efficiency is a measure of the combustion efficiency and we use it as a means by which turbulence can be measured. Care must be taken in measuring the volumetric efficiency as one of the striking effects of combustion-chamber design is the effect on volumetric efficiency at various speeds, particularly when turbulence is produced by intake-gas velocities.

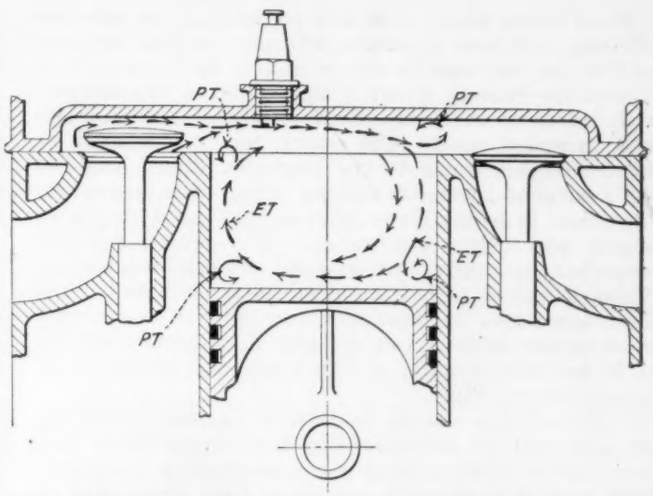

Fig. 10—The Usual T-Head Type Engine Which Must Be Run at High Speed to Get Sufficient Turbulence for a High Mean Effective Pressure and Thermal Efficiency

The ratio of the indicated thermal efficiency to the air-cycle efficiency is used abroad and is known generally as relative efficiency. The loss represented in this efficiency is due to four primary factors which may be outlined as follows, treating the losses as percentages of the air-cycle efficiencies:

(1) Loss due to increasing specific heat at higher temperatures, 17.5 per cent approximately. This must be corrected for the increased volume of the products of combustion, amounting to 3 per cent and reduces this loss to about 15.5 per cent
(2) Loss due to direct radiation, 13 per cent
(3) Loss due to the peak of the diagram, 1 per cent
(4) Loss due to the toe of the diagram, 2 per cent

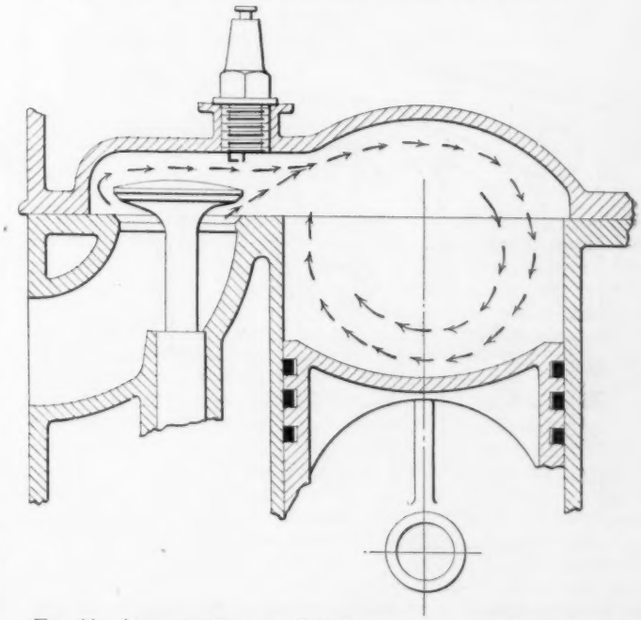

Fig. 11—Another Form of Combustion-Chamber Designed by Ricardo

These losses which total 31.5 per cent of the air-cycle efficiency and give a relative efficiency of 68.5 per cent tend to (*a*) decrease as size of engine increases and, as Ricardo has recently shown with one engine, (*b*) decrease with increased compression-ratio and (*c*) also decrease with increased speed. The reason for (*a*) seems to be the improvement due to the decreased direct heat-loss and a smaller surface-to-volume ratio. The reason for (*b*) seems to be the lower relative heat-loss with higher density and better combustion. The reason for (*c*) seems to be less direct heat-loss and increased combustion efficiency due to turbulence resulting from speed. The above losses may be considered very low and as applying to an engine with a unit cylinder displacement of 130 cu. in. per min., running at 1500 r.p.m. and with a 6½ to 1 compression-ratio.

While turbulence tends to cause an increase in the direct heat-loss, it decreases the dissociation losses and those due to after-burning are brought to a minimum. With a rapid combustion resulting from turbulence it may be expected that the ignition need not be advanced as far as usual. This is found to be true and the spark advance may, all other conditions being equal, be considered an excellent index to turbulence. That is to say, with the same compression-ratio, gas-velocity, fuel-to-air ratio and volumetric efficiency, the spark-advance in degrees may be considered inversely proportionate to the combustion efficiency.

We are gathering data for the purpose of working out a mathematical relationship between spark-advance and combustion efficiency, density and speed.

We have found it possible to attain with a combustion-chamber of L-head type, of the general shape shown in Fig. 11 with cast-iron walls, a relative efficiency of 64 per cent to air-cycle efficiency, as against 54 per cent with a shape approximately like that shown in Fig. 9. With a similar engine of valve-in-head type and at slightly higher compression-ratio, we secured on efficiency of 65 per cent to air-cycle efficiency under laboratory conditions with a gas-velocity of 170 ft. per sec. and a relative efficiency of 56 per cent with a speed of 110 ft. per sec. and slightly inferior carburetion.

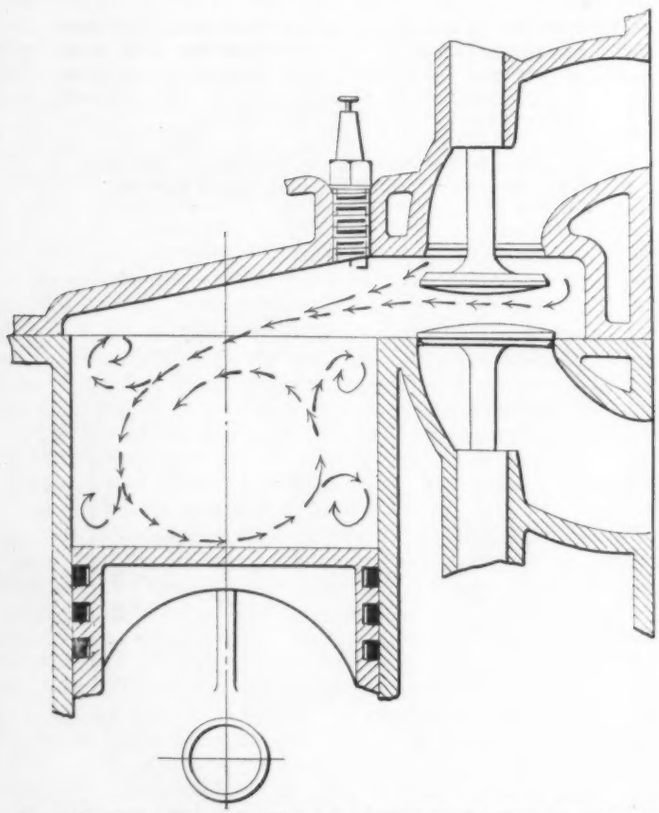

FIG. 12—HIGH SPEED IS USUALLY REQUIRED TO GIVE SUFFICIENT TURBULENCE FOR THE MAXIMUM MEAN EFFECTIVE PRESSURE AND THERMAL EFFICIENCY IN THIS TYPE

The relatively poor turbulence is markedly shown in the greater spark-advance of a valve-in-head engine and the high combustion efficiency due to turbulence is shown in the low spark-advance in forms of combustion-chamber in which the turbulence is highest, such as the high valve-pocket L-head design (See Figs. 5, 7 and 11).

We have found a spark-advance of 64 deg. necessary in a valve-in-head engine of 4 to 1 compression-ratio having a gas velocity of 110 ft. per sec. with a poor carburetion efficiency running at 1000 r.p.m. with a 15 to 1 air-to-fuel ratio.

We have found a spark-advance of only 11 deg. necessary on an L-head engine of the high valve-pocket design at the same speeds and conditions as specified for the valve-in-head engine above. In this case the relative efficiency was very high, offsetting a low compression-ratio.

CONCLUSION

It may be well to recall the effects of turbulence in performance.

(1) By developing high turbulence in a mixture, it is possible to drive off the surface layers of the combustion-chamber and thus force their full contents to contribute to the heat and pressure before the expansion-stroke commences. The fundamental conception of the constant-volume cycle is based on the working fluid receiving all its heat at constant-volume and instantaneously. Neither of these conditions is attainable for obvious practical reasons; however, the wide departure from this ideal with slow-burning mixtures, great spark-advance, low maximum pressures, bad after-burning during expansion, hot cooling-water and exhaust-pipes are marked symptoms of low turbulence, and result in low combustion-efficiency. Since the air-cycle efficiency is constant in any case, a high combustion-efficiency means a high thermal efficiency and since the indicated mean effective pressure is the product of the indicated thermal efficiency, the volumetric efficiency and the energy content turbulence is directly responsible for increased power

(2) Turbulence tends to hurry the combustion of the entire mixture volume without allowing any part to attain high flame-velocities manifested by pre-ignition, detonations or auto-ignitions within certain limits. These limits are difficult to express, there being no generally accepted scientific method for the purpose. Roughly speaking, the common fuels of 1915 and the spring of 1916 furnished by the Standard Oil Co. of Indiana were such as to allow a cylinder of the general form shown in Fig. 5 to run at a 4.6 to 1 compression-ratio without knock. Whereas, it is impossible to run with this shaped combustion-chamber with the present fuels without a knock at a compression-ratio of 3.7 to 1. With a combustion-chamber of the shape shown in Fig. 7 it is possible to run on the present fuels produced by the above-named company with a 4.2 to 1 compression-ratio without knock, whereas with kerosene it is necessary to keep down to a 3.9 to 1 compression-ratio if it is desired to run

without knock and without water-injection. These results are on a heavy-duty engine running at 1000 r.p.m., and with chemically correct mixture proportions. It is obvious that so far as compression-ratios are concerned we have not been able, under the above stated conditions, to offset entirely with combustion-chamber design the decline necessary in compression-ratios to prevent knocking with present fuels

(3) On kerosene-burning engines turbulence has made possible a combustion efficiency at fairly high compression-ratios without use of dopes, water or exhaust gases, giving an indicated thermal efficiency of 26 per cent and an indicated mean effective pressure of 80 lb. per sq. in. without special carbureter designs

(4) Since the fuel of 1915 allowed a compression-ratio of 4.6 to 1, its air-cycle efficiency was 45.8 per cent. The 1921 fuels permit a 3.7 to 1 compression-ratio with an air-cycle efficiency of 40 per cent; therefore the decline in fuel value shows a loss of 14 per cent in efficiency due to a necessary drop in compression with old styles of combustion-chamber. With new designs of combustion chamber, similar to those shown in Fig. 7 and 9, an air-cycle efficiency of 43.5 per cent is possible, cutting down the air-cycle loss due to fuel to 5 per cent. However, since 1916 we have improved the combustion efficiency from 54 per cent of the air-cycle efficiency to a possible 64, a gain of 18 per cent. Therefore, thanks to the turbulence, the fight against increasing end-points and unsaturated compounds shows an indicated thermal efficiency of 28.0 per cent with the 1921 fuel as compared with 24.6 per cent for that available in 1916

(5) Turbulence makes all high speeds possible by speeding up the flame propagation

(6) Turbulence makes high speeds possible without an excessive advance of the spark, and with high mean effective pressure and high thermal efficiency

(7) Due to turbulence, L-head engines of the form shown in Figs. 5 and 9 will be generally superior or at least equal to valve-head engines with respect to knocking, all other conditions being equal, including compression-ratio, mixture ratio and volumetric efficiency

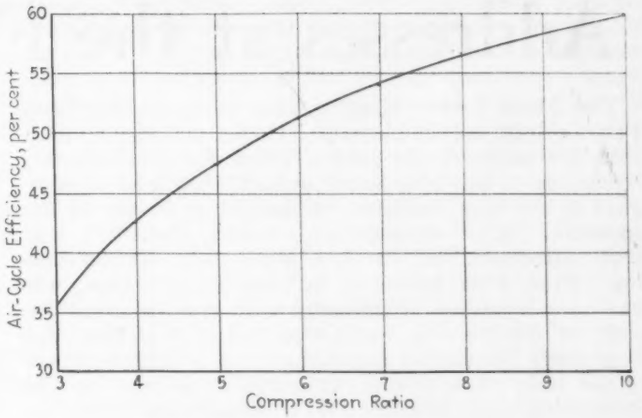

FIG. 13—CURVES OF AIR-CYCLE EFFICIENCY

(8) Turbulence has the effect of preventing knocking at a given speed equivalent to one-half a volume in compression-ratio, whereas dopes can improve the compression between three and four volumes, or an improvement of 7 per cent for turbulence against 33 per cent for dopes in air-cycle efficiency

(9) Turbulence is indispensable to efficient combustion with dopes or without dopes. It is possible to wipe out entirely all the advantage of increased compression allowable with dopes by low turbulence effects

(10) Flame propagation in internal-combustion chambers is influenced by the following factors in order of their importance

- (*a*) The chemical constitution of the fuel molecules
- (*b*) Temperature
- (*c*) Pressure
- (*d*) Turbulence
- (*e*) Mixture ratio
- (*f*) Compactness and shape of combustion-chamber
- (*g*) Location and number of points of ignition
- (*h*) Some property of the spark
- (*i*) Sound-waves in the mixture

RADIO CONTROL OF SHIPS

THE Iowa, it is thought, is the first ship that has been under complete radio or wireless control. There is an unconfirmed report that the Germans had a radio-controlled ship in the recent war. It is supposed to have been armed with a torpedo, but as far as known, no practical results were obtained from it. Before the war the Army was experimenting with radio-controlled torpedoes. It is reported that very satisfactory results were obtained. Under the Army system, torpedoes were launched and their course was directed by a wireless system from the shore. It is planned to use the largest torpedoes in connection with the coast defenses to resist the attack of the enemy fleet. It is understood that the Navy also is making some experiments with the radio-control of torpedoes from battleships.

The Bureau of Steam Engineering is using a radio-control in handling big battleships. It is obvious that this is a more complicated problem, as well as a spectacular achievement. The preliminary reports of the Iowa test are very gratifying. They indicate that it is largely a matter of perfecting the equipment to make the absolute control of the movement of one battleship from another possible. The Iowa was not only steered but her speed was effectively controlled by the commander of the Ohio. Three systems of radio were operated in the Iowa experiment. There was wireless "connection" with the machinery which directed the course of the ship, with the engine and with the pumps which regulated the control of the fire under the boilers and consequently the steam generation. The use of liquid fuel has made such radio-control possible. It would be impossible with a coal-burner. Of course, it will take time to perfect all of the features of the system, but so far no insurmountable difficulties have been met. One purpose of radio-control of a vessel is to provide the fleet with a battleship "in action" as a target. The great military objective, however, is the development of a system for war use. With it old battleships could be used more effectively in bottling up blockaded fleets in ports. With such a system the sinking of the Audacious in blockading the harbor of Zeebrugge in the last war would not have occasioned any loss of life and doubtless have been more successful. Neither would Hobson have been called upon to go into the harbor of Santiago under the Spanish guns.—E. B. Johns in *Sea Power*.

Addresses at the Farm Power Dinner

The Farm Power Meeting held at Columbus, Ohio, Feb. 10, 1921, terminated with a dinner attended by more than 200 members and guests, which was a satisfactory conclusion to this instructive session, especially with regard to the high character of thought expressed by the speakers. After appropriate remarks, President Beecroft introduced Fred Glover as toastmaster for the evening. Prof. J. B. Davidson, of Iowa State College, who has been identified prominently with the American Society of Agricultural Engineers, had as a subject The Engineer's Interest in Agriculture. L. J. Taber, master of the Ohio State Grange, delivered an address on The Rural Situation. President W. H. Stackhouse of the National Implement & Vehicle Association, spoke on the General Conditions of the Times.

ADDRESS OF PROF. J. B. DAVIDSON

AN eminent Canadian asserted several years ago in an address that there are three essential fundamental vocations of man. These three primary vocations are agriculture, meaning the production of food and raw materials for raiment and shelter; home-making, because the establishment and maintenance of civilization depend upon the home; and education, or the imparting to the coming generation of the experience of the past. It is worthwhile to consider this assertion and, I would like to have you, as engineers, consider some of the factors which make for the progress of this great industry, agriculture. We are all interested, for, if we would eat, we must either farm or have someone farm for us. When farmers quit buying tractors and automobiles, people in Detroit and elsewhere are not buying from other sections as much as they would otherwise buy; the people who work at making these machines quit buying clothing and other things because they have less work. Thus we find that the industry of agriculture is very vital. What, then, makes for progress in agriculture?

We have many persons who would solve the farmer's problem for him. Some suggest that the primary interest of agriculture is the maintenance of soil fertility. If this were true, we would find the highest state of agriculture in Korea, for instance, where they have maintained agriculture for 40 centuries; but the Koreans have grown larger crops from the land in the past than they do now and it cannot be true, for there we find almost the lowest standard of agriculture that can be found anywhere in the world. Again, there are those who insist that the primary essential to the progress of agriculture is the production of maximum crops from a unit area. If that were true, we would find on the European Continent the highest standard of agriculture, because Europeans produce more from an acre there than we do; yet we find there a low state of agriculture, indicated by the presence of peasantry. Some suggest that we are unfortunate because the rural population of the country is decreasing. The recent census shows that we have fewer farms in Iowa, one of the States which always stands near the lead in agricultural production, than we had 10 years ago. I assert that the percentage of rural population does not make for a high standard of agriculture because, if that were true, we would find the highest standard of agriculture in India, where 90 per cent of the people live on farms. With the 10-acre dry farm and the 5-acre irrigated farm a very low standard of agriculture is revealed by the standard of living. In California, where they undertook to put the Little Lander idea into effect, people settled on 2 acres or so and were not able to produce enough to afford them railroad-fare to get away. We do not need more people on the farms.

There are others who say that our farm land is running out. We have never had a shortage of food in the United States. The trouble now is that we have a surplus we cannot dispose of. The only time there was a shortage was when the Indians inhabited America; then, at times, there was famine. Last year I talked to a young Chinaman who informed me about the famine conditions in China. I attributed this to a lack of land, but he said that China has millions of acres of virgin land that have yet to be cultivated. This surprised me. I align myself with the new school of economics which insists that what we want is efficient agriculture. In using the word efficient, I refer, in part, to the social structure. The trend of our country depends upon the status of rural life. The health of the people on the farm is a factor. If they are to be efficient, they must be physically sound and strong.

Does capacity for production make for efficient agriculture? Regardless of the other factors, which are important, if we are to have a high standard of agriculture we must have a high capacity for production on the part of the individual. It must be possible for the individual farmer to produce a surplus. Most of the operations carried out on the farm are mechanical in nature. In growing a crop of wheat the operations of preparing the seed bed, planting the seed, harvesting the crop and transporting it to market, are all mechanical processes to which engineering principles and mechanical methods can be applied. The application of power has had a wonderful influence on production. It is possible now for a man to produce 30 times as much small grain today as he was able to produce in 1830. Along with the changes in production ability have come changes in wages and in the mental and physical conditions which surround the farm. We have passed through a development from hand to horsepower methods of farming and motor-tractor farming is here. It is now common to point out the enormous amount of power produced for agriculture by horses, tractors, steam engines and windmills. The aggregate is 25,000,000 to 30,000,000 hp., more than is used in all the manufacturing industries together. This is an inviting field for the engineer. It has been pointed out what an enormous sum would result in 1 yr. if we could effect a saving of 6 per cent in the plowing cost. Few engineers are studying as carefully as they should the economy that might be brought about in connection with the application of power to agriculture.

There are other factors in which the engineer is interested. It has been asserted that 42 per cent of the building construction in the United States is agricultural. Farmers are well housed themselves and they must house their farm animals; so, that is an inviting field for the engineer. There are 200,000,000 acres of land in this country that can be reclaimed by timber clearing, which represents an engineering project. There are 80,000,000 to 150,000,000 acres of land that can be reclaimed by drainage, and many areas can be reclaimed by irrigation. Some think that 150,000,000 acres of land will be reclaimed by irrigation. Many acres can be reclaimed by

following the principles we know about and bringing the land back into productivity by feeding the soil. Again, the engineer is interested in the sanitary equipment of the farm. I am speaking now of the water supply, the sewage disposal, the heating, lighting and ventilating systems of the farm which mean so much in comfort and convenience.

I take issue with the man who insists that there is no engineering in agriculture. It is one of the largest fields for the engineer. There is a great future ahead. I expect to see the day of larger tools, when a man can do even more than he is doing now on the farm. I expect we will have tractors that will go through the entire cycle of intertilled crop production, which is a great problem now. We will have cultivating mechanisms driven direct by the engine instead of having drag mechanisms going between the rows. We will have revolving cutters that will not only make it impossible for a weed to remain but reduce the soil to a good condition of till and provide a mulch. Perhaps we will synchronize machines and cultivate in between the hills. We will have the automatic plow and automatic combination implements. We will have the truck with the corn-husking attachment on the side.

I am rather inclined to think that we are not in a position to do these things at once, and to develop equipment as fast as might be, because manufacturers make their product to sell at a profit and there is not much profit in experimental work. But we shall see a great development in this connection very soon, because the farmer is thinking about getting more for his product and reducing the cost of it. This is a matter worthy of attention. In a survey made in Iowa recently to determine the cost of producing corn, it was found that on 60 farms the farmers use 3 hr. of labor to plow the acre for the corn. With a team and a gang-plow that time can be reduced to 2 hr.; I have done better than that myself. With a tractor the time can be reduced to 1 hr. or less. With hay 5 hr. of human labor was required. In Iowa, it requires 10 hr. per acre to harvest. Regular practice is not anywhere near the best practice.

Engineering, as related to agriculture, has not developed faster because engineering has developed on a professional basis; it has been supported by fee. The farmer has not been able to pay the engineer the fee necessary to support him. It is only in connection with commercial or public organizations that the engineer who is devoting his entire time to the agricultural industry is able to maintain himself. It has been suggested that there might be some conflict between the interests of the automotive and the agricultural engineers, but I think there should be no conflict. Where those interests conflict, there should be the fullest cooperation. It is to our particular interest to see to it that the profession of agricultural engineering develops, because agricultural engineering will be a factor in enabling the farmer to produce a larger surplus. Out of the surplus that the farmer produces he is enabled to build a better home, to equip it with modern conveniences and to provide all manner of mechanical farm equipment. We should have a capacity plan of production in agriculture which will enable the farmer to buy.

ADDRESS OF L. J. TABER

THE rural situation is the largest subject that could be assigned to any speaker just now, so I desire to bring to you with frankness and fairness a vision from the sunshine and the fresh air of the open country, because I am proud to say that every interest I have primarily is in agricultural land or cooperative farm enterprises. I am glad to talk to this audience of engineers because the triumphs of the century that have changed barbarism to civilization have in some degree been the triumphs of the engineer. War has become a problem of the engineer. Agriculture is becoming rapidly a problem of the engineer. Automotive engineers can do more for the future of rural life and more for civilization than any other equal number of men, I might almost say, in this country. The progress of agriculture appears amazing when we realize that it is measured within the short span of the life of men here present; and none of us are very old, although I see before me men who in their automotive thoughtfulness have thought every hair off of their heads and others whose heads the working of their gray matter has whitened. During the thousands of years since the slaves of Pharaoh built the pyramids, the methods of producing the food supply of the human family have been almost without progress or change. It was the task of American engineering and manufacturing genius to develop the marvelous resources of mechanical power, apply this power to the solution of the problems of the farm and make agricultural progress possible. Reviewing the situation as we find it in the country, it is clear that power-driven farm machinery and the prosperity of agriculture are so interlocked that they are inseparable.

There has never been in the Buckeye State any of the radicalism that has marked the steps of agriculture in some States of this Nation, and there will be none unless the financial and manufacturing forces of America are blind to conditions that are developing in rural life. We hear much of deflation. I enter into no discussion of economics in that regard. I know conditions are dark nationally and internationally. All should realize that fact, but there is no need for pessimism. The subject of deflation reminds us of the much heralded farmers' strike. I heard a leader of finance make the statement that the rapid decline in prices would have splendid advantage in that it would bring to us a reduced cost of living. The cost of living has been unnecessarily, arbitrarily and unreasonably high, and the burden has fallen on those who do not live in the country. The deflation of agricultural prices which is being heralded in the industrial centers will be short-lived. The American farmer purchases about 45 per cent of the manufactured articles of this country that are not exported. Deflation is necessary. The largest financial institution in Ohio states in a recent bulletin that the decline in the last 6 months of the farm values of America is 56 per cent. The so-called farmers' strike is not so much a strike as it is the natural operation of immutable laws. The dollar of the farmer has changed in value from the 100 cents of one year ago to the 44 cents of today. It is not entirely a strike; it is simply the working out of conditions. It is true that the farmer is not buying and may not buy for a period, but I believe an adjustment is taking place which will bring to us better conditions in this regard.

If the farmer is without the things which are essential to efficient and economic production, it may be possible for him to do without fertilizer for one crop, but it would not be economical. It might be possible for him to patch up his old machinery, but it would be false economy in view of the existing labor and material shortage. The main thing which is wrong is that those in the country and in the industries at large do not understand each

other as they should. There is no more valuable service that can be rendered today than the furthering of a better understanding among the farmers, the men who manufacture the tools and the engineers who shorten the farmer's labor and increase his efficiency. When those forces understand each other better, they will realize that the prosperity of the one is bound up in that of the other; that by cooperation and mutual agreement they can make the progress which is so necessary for industry and for agriculture.

The automotive engineers and the tractor builders are friends of ours because they have supplied mechanical agencies that tend to keep the boys on the farms, but we must insist upon a higher standard upon the farm along all lines. A farmer told me last summer that to keep his son from leaving the farm he bought a tractor, a manure-spreader, a mowing-machine attachment and a new binder. He said the boy had no desire to go away then. I stayed for supper and found that farmer's wife had to carry in water 100 ft. from a well. Our farming has been done only partially. We must insist on a higher standard of living in the country. The farmer must have sufficient reward to put into his farm home a water system, the vacuum cleaner, the power washer and all the conveniences and attractions that can be found in any other home. When we discuss the future of modern agriculture and power farming, we must think not only of the mechanical part that relates to the farm and to production, but realize that agriculture must be sufficiently remunerative to keep the boys on the farm and hold the girls there as well.

Quantity production is essential, but there will be no permanent prosperity in rural life until we realize that marketing is a function that must be given attention along with production. This may not appear economically sound to the trained engineer, but we insist that no amount of increased production will bring enduring prosperity to agriculture if the marketing problems of the farmer are neglected.

The farmer recognizes his need for good churches and schools and that they are the foundation of good agriculture. He understands that he must have as many commodity organizations as there are commodities to be distributed, such as milk, wool and other distributing organizations. The American farmer and the public have failed to appreciate that the farmer must take a larger share in the conduct of his own affairs. In connection with community organizations that stimulate the social, the educational and the moral life, develop leadership and train people to serve agriculture, we must have commodity and business organizations to look after the larger machinery of agriculture and to secure for the American farmer proper cooperative distribution machinery. There is no socialism, radicalism or communism on the farm. The American farmer desires to become a business man as well as a producer. He has no desire at all to interfere with any of the established methods. Cooperation is here to stay. We are just in the infancy of the greatest organization movement relating to agriculture ever known and it cannot be stopped.

The farmer has no desire for the elimination of the middleman or to control anything but the products of his own toil. He has no desire for a trust, or for favors that are not granted freely to anyone else, but he is insisting that modern agriculture be equipped through organization, education and cooperatve machinery, so that it will be possible for him to take into his own hands the conduct of his own affairs as any other business man would do. The American farmer is preparing to put his own money into his own business. He wishes to shorten the route between the consumer and the producer, not so that the consumer will pay more, but so that the farmer will receive more for his products. The automotive engineer, the tractor builder and the implement dealer will receive more then, and so will society, because better standards will be set up in the country and the equipment that is necessary to maintain those standards will be forthcoming.

Those of the automotive industry who are serving agriculture are serving civilization by improving machinery and by lightening the toil of the men in the country. We are friends and your prosperity is our prosperity. The man in the country is neither suspicious nor critical, although just now he is somewhat pessimistic. But you are going to find the farmer in the market again and, as he begins to liquidate, you will find him putting his money into your pockets, for his own and for your own good.

I cannot conclude without picturing the day when we shall have the independent educated farmers organized. The right kind of organization is for your good and for the good of agriculture and you cannot stop it. Farmers love the institutions of the Republic as their ancestors loved them, realize that there are certain lines beyond which they cannot go and comprehend the responsibilities, rights and duties of all in a community interest. God never made a written contract between you and me, but there is one just the same. It is the divine law. Its slow-working process has left me upon the farm and it has placed you in manufacturing establishments. There is a contract between you and me in that I am to stay on the farm and produce the food, and you are to build the machinery. We are going to work, realizing that this bond of fellowship cannot be dissolved. Some men must stay in the country and some must stay in the town; some must produce tractors, clothing and food, and some must take care of the transportation and distribution. The great plan of God provides a place for us all and, when we fill that place, we will make this country of ours not only a better place in which to farm, but a better place in which to operate a business and a better place in which to live.

ADDRESS OF W. H. STACKHOUSE

THE farm-operating equipment industry and the basic industry of agriculture are so thoroughly intermingled that I find myself unable to discuss the one to the disregard of the other. Realizing the absolute interdependence existing between these industries, the National Implement & Vehicle Association, which represents 93 per cent of the entire output of farm implements in the country, took the initiative some time ago of periodically having informal conferences with the officers of the principal national organizations of farmers. I am a firm believer in organization and the absolute propriety as well as the necessity for organization along sound economic and constructive lines by the farmer, the manufacturer and all other different groups of commerce. When I refer to business I use the term in a sufficiently comprehensive form to include the farmer. I regard him as the best business man in the United States from the standpoint of commercial capability. Very logically and inevitably, the business of this country is undergoing a more or less serious depression that will be more or less prolonged. That is logical because the entire population of this coun-

try has been on a great joy ride since the armistice, but that period has about terminated.

Some illuminating statistics have been prepared and published periodically by the United States Department of Agriculture. In 1820, 95 per cent of the population of this country lived on the farms; in 1920 only 49 per cent of the population was rural. Under the conditions prevailing in 1850 it would take one man over 570,000,000 days to raise the crops of 1920, but under the conditions prevailing in 1920 that one man could raise the crops of 1920 in a trifle over 119,000,000 days. This is a gain of 79 per cent, due almost wholly to the advent of modern farm equipment, intelligently and economically utilized. That constitutes a real achievement in the evolution of agriculture in this country. The major contribution in that achievement belongs to the farm-operation-equipment industry.

It would be folly to deny that this business depression has not affected the farmer tremendously; and it affects adversely every other industry. The only distinction I make in the discussion of this problem between the agricultural industry and all others is that agriculture is basic. The problem before us all today is purely one of economics and I propose to discuss it solely from that standpoint. It is not a problem that can be solved from the standpoint of sentiment. When it comes to a comprehensive analysis of a profound economic problem simply for the purpose of arriving at a solution, that is the time to disregard all sentiment to arrive at an intelligent and approximately an accurate solution.

The most recent statistics regarding crop production and values for the year 1920 place the value of all farm products at some $19,856,000,000, or a trifle over $5,000,000,000 below the value of these products during 1919. I think that the farmer has not lost $5,000,000,000, although it is true he has sustained a book loss. Book losses and actual losses are frequently vastly different things. Whether or not the farmer, as such, has sustained a loss and what his net loss is, it is impossible for him to determine until he has liquidated his holdings, just as in the case of the manufacturer.

This total valuation of farm products at $19,856,000,000 is 100 per cent more than the value of the total products of 1914, the last prewar year. The total value of farm crops during 1920, as distinguished from the more comprehensive term "farm products," was about $11,145,000,000. That is over 80 per cent greater than the value of the crops raised during either 1914 or 1913, and the latter was the banner year up to that time. The value of all animals and animal products raised on the farm during 1920 was 132 per cent greater than during 1914, and that was the banner year at that time. The value of those animal products in 1914 approximated $3,700,000,000; in 1920 the value was $8,700,000,000. The concluding statement is that the value of all farm crops during 1920 was 2 per cent more than the average value during the 5-year war period of 1914 to 1918 inclusive. I quote these statistics to correct the misapprehension many of us have had, due to inaccurate statements regarding these same matters that are made by the unthinking and the uninformed. I submit that the farmers of the United States still unmistakably possess a tremendous buying power. The farmer never has been a profiteer or a striker, and I predict that he never will be.

With further reference to the close interdependence existing between the basic industry of agriculture and the farm-implement industry, let us consider how manufacturers have deported themselves with reference to the prices charged the farmers. Let us see whether they have been culpable of anything that would justify adverse criticism of their conduct in relation to the ultimate consumer as well as to the primary producer, the farmer. The Federal Trade Commission at Washington recently completed a 2-year investigation of the farm-implement industry and stated that in the 6-year period from 1913 to 1918 inclusive the average price of farm implements increased 72 per cent; the average price of all other commodities sold to the farmer, which would affect his costs and profits, advanced 97 per cent; and the average price of farm products of all kinds had increased 118 per cent. These statistics have since been extended up to and including 1920 by a company that is not in the farm-implement business. They show that for the 8-year period from 1913 to 1920 farm implements had increased in price 78 per cent; farm products, 112 per cent; labor, 115 per cent; and all other commodities, 144 per cent. That indicates unquestionably the conservative policy that has been pursued in the matter of price by the manufacturers of farm implements in this country in the past 8 years.

In further connection with this matter, let us consider the relative advance in prices in the same period of the principal commodities entering into the construction of farm implements. I will give statistics which have been compiled by our Association from one of the largest industrial communities in the United States where the principal product is farm implements. We find that in this period steel bars increased 106 per cent; sheet steel, 147 per cent; old rails, 217 per cent; soft-center steel, 144 per cent; pig iron, 218 per cent, although today it is 115 per cent higher than then; malleable castings, 200 per cent; and yellow pine, 175 per cent. Labor increased over 125 per cent and, since 1914, freight rates have increased 101 per cent.

Still holding to the substance of my theme that not only the farmer but every other commercial industry in this country is more or less adversely and seriously affected by the business depression, we find from recent statistics by Dun and Bradstreet that we had 8881 commercial failures in this country in 1920, representing a total of $295,000,000, or $100,000,000 greater than in 1916, and that the commercial mortality in January 1921 is the highest we have had in some 8 or 10 years for that month. In addition, one has only to look to South Dakota to learn that, as the result of practising unsound business methods in violation of all economic rules, some 27 banks failed in the past 4 months. In the last few years it required very little talent, relatively speaking, to be a successful farmer or manufacturer in this country. Our sales were made automatically and likewise our collections. Almost anyone can be a thoughtless optimist in times of that kind. It tests the ability, the character and the mettle of real men to be constructive optimists in times like the present. Through intelligent and persistent cooperation we can reduce the effect of this period of depression to a minimum. That is the only way in which it can be done. We should cooperate most aggressively with the American farmer to see that he is accorded preferential treatment with reference to obtaining the proper amount of financial assistance for his legitimate requirements. Aside from that and treating the farmer as fairly and observing the same rules of ethics that every sound and honorable business man should observe, are we not obliged to share proportionately in the vicissitudes of commercial life in this country and in the world, just as at other times we share disproportionately in the unusual

prosperity of this country and of the world? It seems to me that this is perfectly sound and something we should insist upon.

The greatest misconception has existed in many minds in this country and particularly in the case of a great many farmers as to the propriety of the existing prices of the farm-implement industry as a whole. We are fully aware of the shrinkage in value of farm products. But when, under the powerful stimulus of a great war, it is impossible for us to gratify the demand for foodstuffs and the machinery and equipment required to produce them in maximum quantities, are we not aware that advances in prices do not occur with scientific precision or commence simultaneously, any more than they advance proportionately? The statistics I have quoted emphasize the correctness of that statement. Is it not true equally that, when the turn comes, as it has come, and during the more or less chaotic conditions surrounding a reconstruction period, prices do not decline simultaneously, proportionately, or with scientific accuracy? It requires time, and it is an uncomfortable time, to reach what may be termed a normal basis. Then the prices of all the different commodities strike their respective levels which are never, should not be and never will be uniform, because all things are not worth the same amount and nobody contends that they are. That is precisely the period we are passing through at present. So, let us not forget that, since the price of farm implements did not advance proportionately or simultaneously with that of all the other products, the price will not come down with scientific accuracy.

With reference to a reduction in manufacturers' prices, that time is coming. It will come just as soon as the replacement cost of the manufacturers' product is reduced. I have been asked why the manufacturer does not reduce his price right now and take his loss. If the proposition were as simple as that, he would gladly do it. The manufacturer will sustain his loss. Through the war period and since the armistice the average net profit has been 10 per cent or less on the investment of the implement manufacturer. If I am not mistaken that 10 per cent, minus, will disappear entirely this year when he does sustain his loss on his high-priced inventory. If I reduced prices today 25 per cent, replaced at the higher cost, sold again at the same 25-per cent reduction and replaced again, and all other manufacturers did the same, one-half of us would be in the sheriff's hands within 6 months, as well as two-thirds of the dealers, as would the same percentage of any group of business men. The farmer should not go on a buying strike. This does not mean that he should be silly enough to buy something he does not need, but if some machinery manufacturer produces a tool that costs $10,000 and the farmer can use it economically and reduce his production cost to a minimum, he cannot afford not to buy that tool. If ever a time existed when he should utilize mechanical equipment to produce at a minimum, it is now. We certainly expect him to buy exactly the equipment that will adequately enable him to produce at a minimum cost, but no more than that. The law of supply and demand is in operation. The manufacturer will have to observe that inexorable law, as well as everyone else.

With regard to the unnecessary multiplicity of types of machinery for farm operation, I would say that our association is represented on the Committee of Agricultural Equipment Standards, as are also the Society of Automotive Engineers and the American Society of Agricultural Engineers. As a result of effective cooperation, we ascertained that last year alone we saved the American farmer $10,000,000 by selling implements to him for $10,000,000 less than we could have afforded to sell them had it not been for the campaign toward intelligent elimination. This is an activity that redounds almost entirely to the benefit of the farmer, and indirectly to the benefit of the manufacturer in that it makes the farmer a better customer. One other activity was initiated by our Association in 1917, which was approved by the Government. We instituted repair-week campaigns in January 1918 and have maintained that activity ever since. In February, March and April of this year we divided the entire country into three zones and devoted a week in each zone to advocating to the American farmer that he repair his old machinery and utilize it in preference to buying new machinery.

In conclusion, although the sun is not shining just now, figuratively speaking, we will solve all our problems together and through cooperation. History shows unmistakably that when intricate, irritating and vexatious problems have confronted us we have never failed to find sound, practical and correct solutions of them. That will be the case in this period of business depression which will terminate quickly proportionately as the farmer, the manufacturer, the merchant and the banker cooperate along sound, economic, constructive business lines.

AMERICAN TECHNICAL SCHOOLS

THE first American technical school, Rensselaer Polytechnic Institute, was founded in 1824. This was the only school of its kind for nearly a quarter of a century, until 1847, when Harvard established the Lawrence Scientific School and Yale, the Sheffield Scientific School. The University of Michigan also established in the same year a course in civil engineering. Until the Civil War there were no other schools of this character. In 1862, Congress enacted the Morrill Land Grant Act providing, through grants of public lands, for the endowment of schools to teach agriculture and the mechanic arts. This act immediately stimulated the establishment of technical schools and from a total of 4 in 1860 the number increased to 70 by 1872 and to 85 by 1880. There are now 126 institutions providing engineering courses, 46 of which are land-grant colleges operating under the provisions of the Morrill Land Grant Act. In addition to these, there are 43 other institutions that give some engineering instruction.—T. H. MacDonald.

Aerial Transportation of the Immediate Future

By RALPH H. UPSON[1]

ANNUAL MEETING PAPER *Illustrated with* CHARTS

THE economics of a business is usually worked out after the business in question has become well established. The success of the railroad or the automobile has been necessary to encourage the formation of college courses for the study of them, which is extremely valuable, although it comes too late to be of much service in the organization of the original plan. I am trying to outline in advance some of the factors in the fundamental economics of air transportation which must be recognized even in its original plan and conception, especially in regard to the airship, which requires such a large outlay of capital at the start if we are to expect much success. The extent to which investors will place money in plans of this kind, the extent to which communities will develop landing-fields and the extent to which Congress can be prevailed upon to furnish what aid may be necessary all depend upon the whole subject working out as a real economic factor.

We have three recognized forms of transportation worth mentioning at present; railroad, steamship and motor truck. Of these I would call the railroad and steamship primary and the motor truck secondary, the last named being used for more special purposes. As to the new forms of transportation, the airplane and the airship, in the last analysis it must be left to the investors to decide how far to go. Three questions are typical of the average investor in this connection, and they are worth noting at the start. In considering a new transportation vehicle the first question is, "Will it work?" The attitude expressed in this question is now nearly outgrown. It was formerly the one formula for inventors and investors alike, but the matter of whether an invention will "work" is left entirely now to the men who have studied the subject and proved that they know how to make their inventions work. The next question is somewhat more imminent. We are not yet past the stage where we ask, "Is it safe?" Many of us base most of our calculations on that point. But I am sure that this matter also soon will be left in the hands of men who have proved that they know how to make air-travel safe, with much the same confidence. But, because it is a point often raised at present, it is well to take it into consideration. Safety is relative. There is no such thing as absolute safety; but the relativity of safety must be applied in the right direction. There are certain apologists who argue that we should expect danger in aircraft, that we cannot get something for nothing, that we are getting extra speed and that we should expect to take somewhat more risk. I distinctly disagree with any such sentiment. In fact, all reasonable consistent analysis seems to indicate exactly the contrary; that the more speed we have, the more important the matter of safety is. This will be clear, as applied to passengers, from just one consideration. If the time of a business man is of the utmost value and he is willing to pay the fares which will be required for air-travel, to pay extra for increased speed, he also will value his safety that much the more. He will be unwilling to use a transportation vehicle, no matter how fast, if he must risk his life in the attempt. So, I insist that in aviation work it is not a matter of sacrificing safety to get speed; there must always be speed *and* safety. As a fundamental fact, if any transportation system is worthwhile, it is worth whatever trouble and expense may be necessary to make it safe. There are so many different ways of accomplishing safety that there is absolutely no excuse for failure to make vehicles safe. It is simply a matter of proper design; that is, suitable design, and organizing for the purpose. So, for present purposes, we will assume that safety is a part of the general economics of the subject; in other words, we will take it into account in our cost figures by including the cost of safe design and organization.

The third fundamental question of investors, which we encounter more and more frequently and is the only logical basis for development is, "Will it pay?" I do not refer here to any individual investor. We can take it for granted that any man who puts his money into a business hopes to get some personal profit out of it. I refer here to the broader question of whether an enterprise will pay generally, economically, for society as a whole; after all, that is the only sure foundation upon which we can establish any big industry of this kind. This matter of profit involves some factors that should be of extreme interest to anyone interested in the subject or, indeed, to anyone who is interested in life itself, because transportation is a very intimate factor in modern life.

FUNDAMENTAL FACTORS

The fundamental factors are length of haul, mileage cost, cargo or passenger capacity and the amount of business it is possible to obtain in any one class. The length of haul and mileage cost go pretty much together. I am working out the transportation cost per 1000 lb. per 1000 miles for different lengths of haul. The standpoint that I am taking for this is not passengers, fundamentally, but freight. I realize that this is a somewhat novel procedure, but I feel that it is the more fundamental standpoint, and it can be worked out readily later in terms of passengers. The first thing to do is to determine on certain basic costs; that is, to take a certain typical more-or-less familiar case, the costs of which we know, and then consider how the different items can be classified with respect to their source; especially, to determine how they vary for different other conditions, particularly for changes in speed and size.

[1]M.S.A.E.—Consulting engineer, with Alexander Klemin and Associates, New York City.

TABLE 1—BASIS FOR AIRPLANE COSTS,[2] CAPITAL ACCOUNT

Items	Cost
One airplane, including powerplant, at $4 per lb.	$30,000
One-half of oversize hangar space	15,000
Land, one-eighth of 80 acres	30,000
Shops, etc., one-eighth of total cost	20,000
Offices and Miscellaneous, one-sixteenth of total cost	20,000
Working Capital and Reserve	100,000
Total	$215,000

[2]For one 800-hp. all-metal airplane of 15,000-lb. gross lift; maximum speed, 105 m.p.h.; average landing speed, 60 m.p.h. Costs include a proportional share of all equipment, assuming an average of eight planes on the station at a time.

Table 1 shows the capital account for the base airplane-line. This is simply an assumed layout for an airplane line, based on certain arbitrary assumptions. The only claim I make for the figures is that they are generally comparative for the different transportation vehicles. I have taken as authorities the most optimistic of the experts in their particular lines. It should be noted that the costs are not to be taken as proper for figuring actual rates, profits and the like; in that case we must figure high. In this case I am figuring rather low to obtain comparative figures all the way through. On the capital account, for example, I have charged uniformly 8 per cent interest. Table 2 is the yearly operating account for airplanes under certain assumptions. Some engineers may say that it is too good and that this cannot be achieved with the planes we have available at present. I know it cannot be done with made-over war-planes and, if one has other ideas of what can or cannot be done, by all means let him substitute his own figures, if preferred.

Table 3 shows the general method by which the comparisons are worked out. It comprises a series of columns, headed by the quantity which governs the variation of each of the items. Column 2, for example, comprises all costs which depend only upon the carrying capacity of the vehicle. Column 3 depends upon the powerplant, including fuel. Column 4 depends upon the length of route, which is another way of saying that its costs are those due to the landing and starting of the plane. Column 5 comprises certain expenses due to the handling the cargo itself, which are not at all dependent upon the capacity of the plane, but upon the number of pounds handled, whether distributed between one or a dozen planes. After these costs are summed up in Column 6, the coefficient of variation is worked out for each column,

TABLE 2—YEARLY OPERATING COSTS OF AIRPLANES[3]

Items		Percentage	Cost
Interest on Investment		8	$17,200
Insurance	Airplane	20	6,000
	Terminal	1	800
Depreciation	Airplane Powerplant Renewals	..	70,000
	Remainder of Airplane	20	3,500
	Terminal	5	2,500
Maintenance	Airplane Powerplant	..	20,000
	Remainder of Airplane	..	10,000
	Terminal	..	3,000
Operating personnel	Airplane Powerplant	..	15,000
	Remainder of Airplane	..	10,000
	Terminal	..	10,000
Miscellaneous Overhead		..	35,000
Gasoline and Oil, average 40 cents per gal.			77,000
Total per year			$280,000

$$\frac{280{,}000 \times 1000 \times 1000}{2920\ (103 - 11.5) \times 0.49 \times 15{,}000} = \$143 \text{ per 1000 lb. per 1000 miles.}$$

$$\frac{800 \times 2920 \times 0.75 \times 0.60 \times 0.40}{6} = \$70{,}000 = \text{Theoretical cost of gasoline.}$$

[3]For an 800-hp. airplane on a steady route of 200 miles, flying one-third of the total time; average air-speed, 103 m.p.h. at three-quarter of full power; altitude, 7000 to 9000 ft.; four regular trips per day.

TABLE 3—AIRPLANE UNIT COSTS[4]

Items	Item Varies As: $\frac{1}{C(v-11.5)}$	$\frac{P}{C(v-11.5)}$	$\frac{1}{Cs}$	$\frac{1}{s}$	Total
Col. 1	Col. 2 Per year	Col. 3 Per year	Col. 4 Per year	Col. 5 Per year	Col. 6
Interest	$13,200	$4,000			$17,200
Insurance	4,000	2,800			6,800
Depreciation	4,000	70,000	$2,000		76,000
Maintenance	12,000	20,000	1,000		33,000
Personnel	10,000	15,000	500	$9,500	35,000
Overhead	15,000	5,000	5,000	10,000	35,000
Fuel		71,500	5,500		77,000
Total	$58,200	$188,300	$14,000	$19,500	$280,000
Coefficient	1,330	20,400	700	2,000	
Unit Cost	$30.00	$95.90	$7.10	$10.00	$143.00

[4]Cost, in terms of dollars per 1000 lb. per 1000 miles, equals $(24{,}000 \div [C\ (v - 11.5)])\ \ (6.5 + P) + 700/Cs + 2000/s$.

and then the unit cost per million pound-miles, and the results are combined finally in the general working formula shown.

Tables 4 and 5 show the same line-up for airships. One interesting fact is brought out in this specimen case; the airship capital account is nearly 10 times as much as the airplane account, but the operating cost is only about double, for a carrying capacity vastly greater. The classification of the costs is worked out in a similar manner as for airplanes, except that another variable, size, has been taken into account also.

Fig. 1 shows the general effect of variation in size for a constant speed of 70 m.p.h. The long and tedious work of calculating the effect of size on the carrying capacity, which of course is vital in connection with the unit cost, is omitted. Fig. 1 shows the great effect of size. The scale of volume is at the bottom. Vertically, we have the percentage of cargo as compared to gross displacement, and also the cost of haulage in terms of dollars per 1000 pounds per 1000 miles. The heavy curves at the top are the carrying capacities for routes of different length, running from zero to 8000 miles. It is evident that the size for the largest percentage of carrying capacity increases very markedly with increase of distance. One would expect this, but I think no one expected such huge sizes. For instance, a route of 4000 miles, which corresponds to many feasible distances across the Atlantic, requires a ship of 3,000,000 cu. ft. of gas capacity to negotiate it at all at a speed of 70 m.p.h. The dirigible R-34 had a speed of slightly over 50 m.p.h. To obtain reasonable economy, judging from the cost curve, we must go up to at least 10,000,000 cu. ft., and for maximum economy to about 50,000,000 cu. ft., which is far larger than anything we have at present. I have not assumed any radically new discoveries in the way of design or other improvements of that kind, other

TABLE 4—BASIS FOR AIRSHIP COSTS,[5] CAPITAL ACCOUNT

Items		Cost
One Rigid Airship of 2,000,000-cu. ft. capacity; maximum speed, 80 m.p.h.	Powerplant, at $5 per lb.	$100,000
	Remainder of Airship at $8 per lb.	500,000
One half of oversize hangar space, or one single hangar		600,000
One Mooring Tower and Equipment		50,000
Land at one Terminal, one-half of 160 acres, ½ mile square		200,000
One-half of cost of Gas Plant, Powerhouse and Airships		100,000
Offices and Miscellaneous, one-quarter of total cost		100,000
Working Capital and Reserve		600,000
Total		$2,250,000

[5]For one airship and its own share of equipment, assuming two airships handled per day at each terminal.

than mere size alone. I have worked out the steamship, the railroad and the motor truck on rather a similar basis, using the best authorities obtainable for the effect of length of haul and the mileage cost.

Inherent Value of Speed

We come next to the factor of time-value, or the inherent value of speed. That is already a well recognized factor in American transportation, but it is especially important in aircraft, which claims speed for its great prerogative. In fact, it would not be very far outside the limits of what is justifiable to agree to forget about everything else and to say that if the airship and the airplane cannot succeed on a basis of speed, they cannot succeed at all. The method of measuring the time or speed-value is of course an important matter. I have taken that in the very simplest terms, as represented by the value of any given goods per hour per 1000 lb.; that is, if we have 1000 lb. of material of some kind on which it will pay us to save 1 hr. of time, we figure what the saving is and that is the gage of how much we are able to pay for increased speed. So, we will take the time-value of the cargo in terms of dollars per 1000 lb. per hr. For example, suppose some fruit is ordered from California for delivery in New York. If it came by the ordinary slow freight, a large amount would spoil. It costs more by fast freight but the net economy is greater if we save enough of the consignment to make up for it. This is the big factor that must be taken into account in all analyses of air-transportation proposals.

Fig. 2 shows the development of the principle for one particular type of carrier, the airship. This is prepared from about 1000 calculations, covering different conditions of use. The same method can be applied in principle to any form of transportation. The vertical divisions with figures at the bottom represent the length of route between stops. The horizontal divisions with figures at the left represent the time-value of the cargo per 1000 lb. per hr. Taking a route 3000 miles long and a cargo with a time-value of $1.70 per 1000 lb.; starting with a value of $1.70 at the left, we run horizontally over until we strike the 3000-mile mark, and spot the intersection; the curved lines running through the same point give the other data that are sought. First of all, take the line which is marked "transportation cost." This shows an actual cost of transportation of $53 per 1000 lb. per 1000 miles. The size of ship for the maximum ultimate economy in this case is 41,000,000 cu. ft. and the speed at which it is most economical to travel is 349 m.p.h. It will, of course, be said that these sizes are out of reach of present construction. They are, to the extent that we have not produced them yet but, as mentioned before, this requires only engineering work and involves no new discoveries.

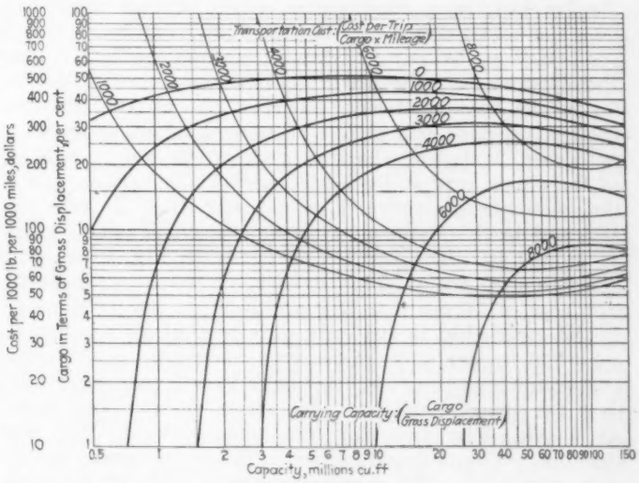

FIG. 1—CAPACITY AND COST CURVES OF COMMERCIAL AIRSHIPS BASED ON AN AVERAGE AIR SPEED OF 70 M. P. H.

Fig. 3 is a general combination in a rough way of different transportation systems that will be available after proper organization of the aircraft systems. This is worked out on a somewhat different basis, to simplify it. On such a broad scale we cannot include all the different routes that we did with the airship alone; hence we take for each of the primary systems, the railroad, the steamship and the airship, an assumed route of 1000 miles. For the secondary systems of motor truck and airplane, we take a route of 200 miles each. Along

TABLE 5—YEARLY OPERATING COSTS OF AIRSHIPS[6]

Items		Percentage	Cost
Interest on Investment,		8	$180,000
Insurance	Airship	10	70,000
	Terminal	1 to 2	17,000
Depreciation	Airship Powerplant Renewals	..	180,000
	Remainder of Airship	30	150,000
	Terminal	5	48,000
Maintenance	Airship Powerplant, overhauls, etc.	..	50,000
	Remainder of Airship, current repairs	..	30,000
	Terminal, current repairs	..	20,000
Operating Personnel	Airship Powerplant	..	40,000
	Remainder of Airship	..	30,000
	Terminal	..	120,000
Miscellaneous Overhead		..	150,000
Gasoline and Oil, average, 40 cents per gal.		..	290,000
Hydrogen ($1 50 per M, materials only)		..	25,000
Total per year			$1,400,000

$$\frac{1{,}400{,}000 \times 1000 \times 1000}{4380\ (70 - 10) \times 0.336 \times 150{,}000} = \$106 \text{ per 1000 lb. per 1000 miles}$$

[6]For a 2,000,000-cu. ft., 2480-hp. airship, on a steady route of 1000 miles daily, except when laid up for repairs. The ship is assumed as being laid up one-half the total time and to be running the other half of the time at an average of two-thirds the maximum horsepower, giving an air-speed of 70 m.p.h.

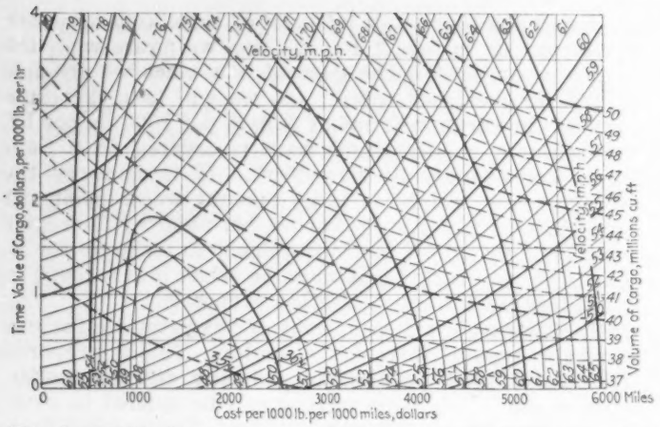

FIG. 2—CURVES SHOWING THE ECONOMIC VALUE, SPEED AND COST FOR CARGO OF VARYING TIME VALUE CARRIED OVER VARYING DISTANCES

the bottom we have the net effective speed in miles per hour. In Fig. 2 it was in terms of the air speed of the airship but, in a combination chart of this kind, that does not mean anything. A fast freight-train on a railroad may go 17 m.p.h. while it is running but it may spend as long a time waiting for other trains to get by. So it has been necessary to work out all the different factors involved and arrive at some kind of estimate of net speed, including the time required to get in and out of terminals, and to load and unload. In explanation of the motor-truck curve I would say that I have not assumed in this case any time or cost charge for loading or unloading. The vertical divisions in Fig. 3 are on a logarithmical scale. This scale runs from a transportation cost of 10 cents to $10 per 1000 lb. per 1000 miles.

The steamship is the only carrier that gets below $1 per 1000 lb. per 1000 miles even under the most favorable conditions possible. Actually, it will cost more than that for usual conditions, including partly filled boats. As I said, Fig. 3 is for ideal conditions all the way through. The railroad comes next in cost and the airship next to it. The airship curve is very nearly horizontal until it finally shoots up when it gets to about 100 m.p.h. It is usually assumed that the airplane exceeds the airship in speed; but it must be noted again that Fig. 3 shows effective speeds and not the actual speeds; we are basing our figures on what we have in actual operation at present. It is a perfectly logical development from present knowledge and material.

The distinctive fields for these different transportation systems are shown in Fig. 3 in the form of shaded areas. The line of figures below the speed figures gives the

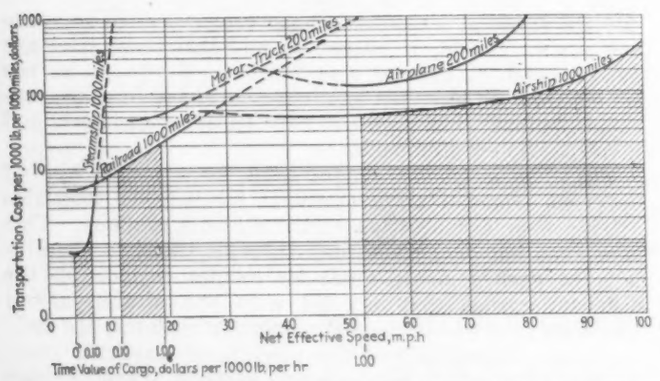
Transportation Cost per 1000 lb. per 1000 miles, dollars
Motor-Truck 200 miles
Airplane 200 miles
Airship 1000 miles
Steamship 1000 miles
Railroad 1000 miles
Net Effective Speed, m.p.h.
Time Value of Cargo, dollars per 1000 lb. per hr

FIG. 3—COMPARATIVE COST OF FREIGHT TRANSPORTATION BY STEAMSHIP, RAILROAD, MOTOR TRUCK, AIRPLANE AND AIRSHIP

time-value of the cargo in dollars per 1000 lb. per hr. The economic range for steamships is from zero to 10 cents per 1000 lb. per hr., which is represented by the shaded area running from 4 to 7 m.p.h. The railroad starts where the steamship leaves off, which makes it appear paradoxical to have a gap in the speed-range. However, reflection will show why it occurs. The economic railroad-range starts at 10 cents and runs up to $1 per 1000 lb. per 1000 miles. I am assuming that one might ship by either water or rail. Again, beyond the railroad speeds we get a big gap up to where the airship begins to be effective. It is not a gap in an economic sense but from the practical standpoint of speed. The airship does not begin to be able to compete with the railroad, with an effective speed of 19 m.p.h., until it reaches about 52 m.p.h., which includes landing and all else; economically it starts where the railroad leaves off, at $1 per 1000 lb. per hr. The motor truck and the airplane cannot be worked into this particular scheme because the latter's chief value depends upon the special uses to which it can be put. This is inclusive of non-schedule work, for instance, and all work of limited capacity, where the carrying of limited loads is required and it is necessary to make exceptional speed over short distances with small loads; finally, in the case of the motor truck it includes the supreme advantage of being able to deliver to destination.

TIME-VALUE CARGO CLASSIFICATION

I will outline briefly in practical terms what it means to classify cargoes according to time-value. For the steamship, which worked out from zero to 10 cents per 1000 lb. per hr., this includes all bulk cargo up to a capital value of $10 per lb., which comprises everything in the nature of coal, ore, stone, wood, castings or anything of similar nature that is not affected by time, other than a moderate interest charge on the investment. For railroads the economic range is up to $1 per 1000 lb. per hr. This includes all non-perishable bulk cargo up to $100 per lb. capital value; the airship starts from there and goes on up. So, it is evident that until we reach such things as jewelry, gold and silver, the capital value does not have much influence; but items that have perishability, such as news value, or human value, including passengers, mail and anything of that type in which time itself is of importance, do make a huge difference. I cannot enumerate all of the different articles which belong in this classification. Among other things the aircraft class includes all mail and practically all passengers, for long routes. The passenger problem is a study in itself.

One thing that must be kept in mind in all these comparisons is the difference between day and night. I have worked the points out on a uniform basis to be consistent, but most commodities and practically all passengers will pay more for the saving of time in daytime than at night, so that any carrier which is limited to daytime travel is under a very great disadvantage. I hope that the airplane will be worked up to overcome that disadvantage soon. For the airship, we can say now that it is easier and safer to handle at night than in the daytime.

As to the future, I have used the word "immediate" in the title of this paper from the standpoint of present knowledge and the materials available rather than from that of time itself. We are on the threshold of aerial navigation. We have airships in sizes up to 2,000,000 cu. ft. that could be run at a very fair profit with goods

of a time-value of $4 per 1000 lb. per hr., or with passengers whose time is worth $8000 per year or more. This is for airships which are in operation at present. The transportation cost can be cut down more than 75 per cent merely by standardization of methods, organization for the purpose, designs which are suitable and, particularly, enlargements in the size of airship units. In this respect I believe that construction and operation must go together at the start. The more closely we can put them together, the better it will be. Furthermore, airships and airplanes should be operated simultaneously and in close cooperation, because they reinforce and supplement each other in almost every possible way. The general tendency at present is to get away from thinking in terms of any particular types. We are coming to the time when, with the growing recognition of the importance of air-travel development, we will not talk so much about designing the Zeppelin type of airship, the all-metal airplane or any other particular type. Instead, we shall go after the suitable type as an engineering problem and work it out to best suit the conditions. When we shall have done that, we will find that nothing we have done in the way of calculating the amount of available business will approach the actual possibilities. When telegraph lines were first being put in 100 years ago and even more recently than that, particularly the cable laid across the Atlantic, the question of what business the lines would attract might have been asked. Then we were in the position of having to charge rates for the transmission of messages over 100 times as much as those for transporting letters over corresponding distances. It might have been argued that no message could be so important as to justify such a large increase in cost. It is impossible to analyze a new business completely. The interesting fact is that the establishment of the telegraph lines and cables created their own business in large measure. In the case of the airship, when we are so organized that we have a network of airship transportation all over this country, it will be feasible to segregate and specialize our different manufacturing industries much more closely than we do at present. We could produce all our milk on one central farm and ship it to every point in the United States for a few cents per quart. I do not say that this will be done but such a thing is possible.

APPENDIX

The assumptions used as a basis for the calculations are as follows:

(1) All carriers are considered as being fully loaded
(2) The most economic size and number of units are considered, according to Tables 1 to 5
(3) The present methods of design, construction and operation are considered, with an allowance made only for change in size and standardization
(4) Invested capital is charged at 8 per cent per year

Fuel cost is taken as follows:

(1) For the steamship, fuel oil at $18 or coal at $7.70 per ton of 2240 lb.
(2) For the railroad, coal at $6 per ton of 2000 lb.
(3) For the motor car, gasoline at 30 cents per United States gal.
(4) For the airplane and the airship, gasoline at 35 cents per United States gal.

Inclusive of construction cost, materials are assumed to cost as follows:

(1) For the steamship, 23 cents per lb. for the powerplant and 12½ cents per lb. for the remainder, which is mainly of steel
(2) For the railroad, locomotives at 18 cents per lb. and 8 cents per lb. for the remainder, which is mainly of steel
(3) For the motor car including the powerplant, 80 cents per lb., mainly of steel
(4) For the airplane including the powerplant, $4 per lb., utilizing steel and duralumin
(5) For the airship, $5 per lb. for the powerplant, mainly of steel; and $8 per lb. for the remainder, utilizing duralumin and fabric

The cost per mile is estimated on a basis of great-circle distance. For the steamship, railroad and motor car the average actual routes assumed are 33 per cent greater than the great-circle route; for the airplane and airship, the route is the same as the great circle.

An allowance of 6 per cent is made for heavy seas in the case of the steamship; about 40 per cent for switching and the like, slightly varying with speed, for the railroad; and about 10 per cent for bad roads, towns and the like for the motor car, varying slightly with the speed. For the airplane, the average cruising speed is taken at three-quarters of full power, further reduced by 11½ m.p.h. to allow for average winds. The average cruising speed of the airship is taken at two-thirds of full power, further reduced by 10 m.p.h. to allow for average winds.

The terminal time in and out, including the handling of the cargo, is from 4 to 8 days for the steamship, depending upon its size; 1 to 2 days for the railroad, depending upon the speed; none for the motor car; 1 hr. for the airplane; and 2 hr. for the airship. No allowance is made for delivery, which is too variable to consider.

The proportion of running time per year is about 55 per cent for the steamship, varying slightly with speed and size; 12 per cent for the railroad and 50 per cent for the motor car, varying slightly with the speed; 33 per cent for the airplane; and 50 per cent for the airship.

Discussion of Papers at the Chicago Truck and Tractor Meeting

THE discussion of the papers presented at the recent Truck and Tractor Meeting of the Society included written contributions submitted by members who were unable to be present and the remarks made at the meeting. In every case an effort has been made to have the authors of the several papers reply to the discussion, both oral and written, and these comments, where received in time for publication, are included in the discussions. A brief abstract of each paper precedes the discussion, with a reference to the issue of THE JOURNAL in which the paper appeared, for the convenience of members who desire to refer to the complete text as originally printed and the illustrations which appeared in connection therewith.

TRACTOR SERVICE REQUIREMENTS

BY J. C. THORPE

THE paper treats of the service, commercial and technical aspects of the subject in turn. The author calls attention to the fact that there can be no such thing as free service, because the customer pays in the end, and gives a specific definition of service. He argues that the engineering departments should urge upon merchandising departments intelligent distribution through dealers, the stocking of an adequate supply of parts and the maintaining of a well qualified mechanical force for the purpose of making engineering development work in the form of farm power automotive apparatus effective.

There is a great need for a suitable system of training mechanics for tractor service work, and there should be a definite plan to assure that men making repairs and adjustments in the field are well qualified.

In conclusion, the author pleads for continued consideration of the subject of accessibility of parts in tractor design, the use of better materials, reduction of weight and the furtherance of a program to increase the number of tools driven by tractors in farm work. [Printed in this issue of THE JOURNAL]

NEED FOR GREATER SERVICE ACCESSIBILITY IN CAR DESIGN

BY T. F. CULLEN

OF the various items of expense in connection with maintaining a car, depreciation probably is the largest single one and insurance, garage expense, repairs, adjustments, tires; gasoline and oil follow in about the order given. Improved service accessibility tends to reduce repair and adjustment costs by decreasing the amount of repair labor necessary and to retard depreciation by enabling the owner to maintain his car in good running order at a minimum expense. Moreover the fact that a car is unusually accessible for all classes of repair work will enhance its resale value. After elaborating these statements, the author reviews the present status of car design for service accessibility and presents a table showing the comparative service accessibility of 40 representative cars on 25 typical service operations, afterward stating the possible improvements suggested by this survey and illustrating them by diagrams. He then discusses the possibilities for improvement in current models of cars. [Printed in the March, 1921, issue of THE JOURNAL]

THE DISCUSSION

PRES. DAVID BEECROFT:—When Mr. Thorpe spoke of the trinity of cooperation in service, he linked together the manufacturer, the dealer and the owner, and again brought out the thought that too often the engineer is confined to the laboratory and fails to follow his product. In these days when resistance arises, sales resistance in particular, the influence of it comes against the sales end, then against production and lastly against the engineering end, but the engineer can play a much broader part than he has in anticipating these conditions. I hold that only part of the time of the engineer should be spent in the laboratory, and that he should be one of the outside investigators or have in his department or organization men to carry on outside investigations. Why should all outside investigation be left to the sales department when the engineer should be better qualified to interpret and translate into manufacturing and engineering requirements the environment that the apparatus must operate in? I sincerely hope that the engineer will branch out and that his department will comprehend not only a sphere of influence but a sphere of investigation. I believe that the peaks of the curve of sales, where sales resistance seems almost too great, can be largely flattened out. Perhaps there will be none if the engineer investigates the requirements and better adapts the design of his apparatus to those requirements.

Regarding the service end of which Mr. Cullen spoke, I spent a week in going through the State of Wisconsin, devoting my entire time to service organizations. I am pleased with the great progress that is being made throughout the country on what is known as the fixed-price system in charging for service. No matter what the apparatus is, the repair stations sell service. If a motor car is driven to a service depot, before it gets inside a representative hears the complaint of the owner,

makes a complete examination, fills out a chart and enters on that chart definite charges for all needed work. He has a complete record made up in which an accurate average time for each particular job has been arrived at, in his own and in other shops. This service work will come back to the engineering department in this way. In one place the charge is $12 for grinding valves and removing carbon, while just across the street the charge is $16 for the same job on an engine with the same number of cylinders. The public will demand an explanation of the difference in price. This fixed-price system is inducing the public to think of service and of accessibility in terms of dollars and cents.

Some time ago I had a repair bill for $121 on which 96 hr. in labor was charged on one line without any other explanation. That labor was at a little over $1 per hr. That kind of a bill never drives home the story of the relationship between service and dollars, but with the fixed-price system in which the owner gets his bill with the amount in the column at the right for each operation, he sees every item, is set thinking and translates the accessibility of his car into dollars and cents as he never translated it before. This movement is gaining great headway. Two distributors of one of our largest manufacturers have worked the system out and had it in operation for 1½ months, and 16 other distributors located throughout the country have sent their service men to the distributors to study the problem. Within a few months they will have the system in operation. They find that there is a greatly improved relationship between the owner and the dealer when the owner is informed in advance what repair work will cost him. One of two dealers who sell rival cars on opposite sides of the same street told me that when he took in exchange for a new one a car sold by his rival across the street, he never thought of sending that car over to the man who sold it to have it repaired because he felt he would be imposed upon. On the basis of the fixed-price repair system he would take in the car sold by his rival and not attempt to overhaul it but have it overhauled by the man who sold it.

Bringing this back to the engineer, the public is being educated on what service means in dollars and cents; I think it is very important at this time that we take due recognition of that. I feel that the engineer must get out beyond his laboratory. The laboratory is unquestionably his field, but he must go beyond that. We might explain that by using as a parallel the fact that we are all very much puzzled as to the commercial application of aviation, and as to who will work it out. Who is to carry on the investigation? There is nothing to sell, there is no salesman and the buyer does not know what to buy. It is the engineer's duty to go out and study the conditions and then to meet them by efficient and economical design. If that be true, it is equally true in the fields of the passenger car, the tractor and the motor truck.

DENT PARRETT:—We who have had experience in the tractor business have encountered many problems in designing the machine so that it can be taken care of easily. A motor truck or an automobile experiences some trouble, but such a vehicle can be towed into a service station very readily. With the tractor, very often the work has to be done in the middle of a large field with no facilities at hand. For that reason, it is even more important that the various parts which require attention on a tractor can be reached without removing a number of other parts. In the later tractor designs this has been taken into consideration and real progress has been made in this respect. There are many opportunities for further improvement, so that any part can be removed in the field without the use of special facilities.

H. L. HORNING:—It is our custom to make our service men acquainted with laboratory methods and our laboratory men are sent out on the road to settle the difficulties which are met by the men who are using our product. It is our practice to make both the research and service men exchange positions. We find that this gives the most satisfactory result in the end. We feel that a research and laboratory man should be able to see the results of his work in the field just as the artillerymen need someone to tell them where their shots are hitting. We have been able through laboratory methods to improve the field performance to a point we never reached without laboratory methods. We find that our book on Care and Operation is the most eagerly sought printed matter we turn out. It is being used by a great many who are not using our engine. People are anxious to obtain knowledge, but are limited in their resources.

L. M. STELLMAN:—We are interested in bringing the subject of service accessibility to the attention of the entire profession. We were interested in the chart in Mr. Cullen's paper which shows the comparative service accessibility of 40 representative automobiles on 25 typical service operations. On account of some omissions this chart does not seem fair because, where an item is considered perfect, 4 points are allowed in connection with the score of that particular item. Further, where an item is left out because no trouble was encountered, no points are allowed for that item. Taking the case of car No. 18, for instance, for 5 items the count is left out which permits 20 points to be left out or allows 80 for a perfect score. Instead of having a perfect score, this particular car has 76 on an average of all operations, 19 points being left out in connection with its score. Figuring 19 points out of 80, Mr. Cullen derives approximately 76 per cent. If the 19 points were figured on the basis of 100 the average of all car operations would be approximately 82 per cent.

We have considered some additional points and offer them for discussion.

(1) Designs should provide for accessibility in lubricating, and lubrication should be required less frequently on parts such as spring pivot bolts, driveshaft and steering connections. Further, the parts to be lubricated should be divided into three classes: (*a*) engine, (*b*) fast-moving or heavy-duty parts and (*c*) minor parts such as brake-rods

(2) All nuts and bolt-heads should be of hexagonal form and have sufficient clearance around the head so that commercial socket-wrenches can be used

(3) Cap-screws should be made sufficiently strong to withstand the abuse of quick removal and reinstallation without undue care

(4) Where gaskets are used to prevent oil leakage, the cap-screws should be sufficiently close together so that an average mechanic can get a tight joint and freedom from bulging due to any excessive tightening of cap-screws

(5) Felt washers on front and rear wheels should be replaceable readily without too much care being required

(6) Wear should be localized in small and relatively inexpensive and readily replaceable parts. It is often better to have a part wear more rapidly and be easily and quickly replaceable with a small amount of labor, than to have a longer-wearing part that involves expensive replacement

(7) The expensive material and labor should be used for

the parts that are most enduring, bushings or simple parts which can be made cheaply, being inserted to take the wear, as in the case of drive line universal joints

(8) Wiring should be arranged so that it can be checked up readily, no connections being in inaccessible places. It is better to have all wiring run to a central switchboard

(9) The squeaks and rattles in the body and in the sheet metal work, such as the guards, should be eliminated, as well as the rattling of doors and windows of closed cars

(10) Easy adjustment of transmission and rear-axle bearings should be provided. The bearing installation parts should be made simpler, more easy to handle quickly and so that they can be reassembled readily at a repair-shop without consequent oil-leakage

ENGINEERING ANALYSIS APPLIED TO TRUCK SELLING

BY N. J. OCKSREIDER

IN this day of transportation engineering, the requirements of each customer must be diagnosed accurately and the economic waste due to wrong selling eliminated. Stating that 32 classes of trades, divided into 350 subclasses, use motor trucks, the author expressed the view that, in applying the science of selling by analysis, it is necessary to know the cost of shipping every pound of goods, deducing in turn the correct size of truck for a given kind of work.

Referring to the fact that a truck cannot be designed to stand up under all conditions and that selling a truck which is unsuitable for a particular task means a dissatisfied customer, the author gives the opinion that a truck of mediocre merit will in many cases perform more satisfactorily than the best truck built operating under improper conditions.

The author makes a broad-minded and valuable contribution in his statement of the factors to be observed in determining the proper type and size of truck to meet a given customer's requirements in the most satisfactory manner, pointing out the many advantages derived from the making of unbiased recommendations and taking all steps possible to prevent overloading.

THE DISCUSSION

CHAIRMAN B. B. BACHMAN:—I think Mr. Ocksreider summed up the situation rather tersely in recognizing that some of the competitors of his company are operating under the same general plan, possibly calling it by a different name. I am reminded in that respect of the similarity of what we have been pleased to call "efficiency engineering" in production lines. To draw a parallel, there is no question that in production lines the application of so-called efficiency methods has been of inestimable benefit, and that without the application of them our present system of production would be impossible. However, with the successes that have been accomplished and the presentation of principles which is possible only in the abstract, there have been those who considered themselves competent to take partial expression of principle and apply it in hidebound form. The results have been unfortunate. Selling is undoubtedly a science, just as is the design of an article or the production of it. As science has been slighted in engineering and in production, so it has been slighted in selling, but probably to an even greater extent. Mr. Ocksreider said that success in the application of correct methods depends upon the application of commonsense principles. It seems to me that in business engineering, production or selling, it all comes down to a basis of commonsense. Unfortunately, that is not such a common possession as its name indicates.

P. M. HOLDSWORTH:—In making analyses such as Mr. Ocksreider describes there must be some cases in which a Packard truck is not found to be the very best truck for the work. What would be the recommendation of the man that made the anlaysis in such a case?

N. J. OCKSREIDER:—We advise the customer frankly if a Packard truck is not fitted for his needs; or if horses are the better equipment. To give a concrete example, we had a case recently in which we analyzed the prospective buyer's needs. He thought that he could improve his hauling problem with the aid of a truck. Our salesman thought so at the time. After the analysis was completed we found that a truck, particularly of the size which we build, did not fit his needs. He had to do one of two things, retain his horse equipment or buy a ¾-ton vehicle. We reported accordingly and did not sell him a Packard truck.

MR. HOLDSWORTH: — Under certain circumstances, would you recommend an electric truck?

MR. OCKSREIDER:—Yes, we have done that. A particular instance is in the case of the Curtis Publishing Co., of Philadelphia. We analyzed its problem some time ago, recommended electric vehicles and it is now operating them.

S. E. BATES:—In the analyses are the different kinds of trailers taken into account and recommendations made accordingly?

MR. OCKSREIDER:—Yes.

MR. BATES:—There are probably 10 to 20 more kinds of trailers offered than of trucks.

MR. OCKSREIDER:—We take the requirements of the problem and prescribe absolutely the thing that we think will solve it with as nearly 100-per cent efficiency as possible. We have to recommend trailers in a large number of cases.

F. J. SULLIVAN:—What does the Packard company do when it makes a recommendation to a purchaser of trucks and after the trucks have been purchased the owner does not adhere to the recommendation, but overloads them for example?

MR. OCKSREIDER:—We protest sometimes; we try to follow the matter through, although it is difficult to keep a customer from overloading. When we make a survey we point out the consequences that can be expected and the inefficiency caused by overloading. We take into consideration deliveries and point out to the purchaser that he will hurt his own efficiency. If he persists, we are absolutely helpless. We often go to the drivers when they are out on the street with an overload and caution them.

J. G. CARROLL:—The work of the large electrical manufacturing companies in the transportation field is really pioneer work. For example, the installation of a mine-

haulage system involves a thorough study of the customers' underground conditions. The companies do not recommend any equipment that would in any way increase haulage costs for the customer. If their own equipment does not fit, they tell the prospective customer so and recommend the size of the equipment he needs, the number of units and the method of installing the entire system. They give him also relative operating costs as closely as they can. This sort of procedure results in a transportation system that is as highly efficient as it is possible to make it. In the past some of the electric-truck companies have failed due to their not having analyzed the conditions under which the trucks had to operate. There were many complaints which gradually worked against the companies, until today very few of the original electric-truck firms are in existence. I have been connected with the application of motors in the electric-truck industry since it first started. I have seen companies grow up and drop away. Customers appreciate the advantage of being able to secure expert assistance from manufacturers in the solution of their transportation problems.

THE APPLICATION OF STEAM POWER TO AN AUTOMOTIVE TRUCK

BY L. L. SCOTT

THE paper describes the steam-operated 2-ton truck developed by E. C. Newcomb and the author. It has a direct drive-shaft from the engine to a rear axle worm, with a 5 to 1 gear-reduction at the axle, and is operated without any transmission or clutch. The engine has been simplified since the author's first report on it in 1919, the changes relating to valve-gear, crankshaft and cam design. After presenting illustrations and describing them, the author gives nine specific advantageous features in this steam powerplant and comments upon them, submitting charts of torque curves which are analyzed. The engine control, fuel, oil and water consumption are next described and discussed and the results of acceleration tests are then shown in tabular form, with comments thereon. [Printed in the February, 1921, issue of THE JOURNAL]

THE DISCUSSION

A. L. NELSON:—With reference to Mr. Scott's discussion of the steam engine there is one point in comparing it with the internal-combustion engine which I think we should not fail to consider. Apparently he assumes that the inefficiency of the gasoline engine at partial loads will continue to remain as great as it has been. We should not assume that the internal-combustion engine will not be developed further. I believe that there is a very good chance of increasing the efficiency of the internal-combustion engine, not at full loads particularly but at the loads under which the engine is used in a truck. I think it would be well worthwhile to make comparisons with this in view.

WILLARD J. GRAMM:—How does Mr. Scott take care of the problem of freezing in winter?

L. L. SCOTT:—It is taken care of in one way by putting alcohol in the water. The water mileage in cold weather is such that this can be done without excessive cost. If the truck is being operated every day, it is not necessary to do anything for the reason that all parts containing water are under the hood. Freezing will not take place because in our particular arrangement there is about 4 in. of refractory material at the bottom of the boiler that retains heat for from 14 to 16 hr. In the event of freezing, the boiler, for example, will not be damaged in any way. The tubes will withstand a pressure of about 30,000 lb. per sq. in. and ice at that pressure is impossible. We are using alcohol right along in our touring car and our truck in cold weather.

Mr. Nelson spoke about the future. There are possibilities of all sorts of things. We have been working with the internal-combustion engine for many years and are making comparisons with what we have today. I mentioned also the possibility of future developmet of a steam plant that can show much greater efficiency than has been shown with steam plants to date. Taking the two types of apparatus as they are today, we are able to show a higher fuel mileage on a lower grade of fuel. Of course, there are many other things to take into consideration besides that one point, such as the ability to burn the fuel regardless of its cost, the cost of oil, repair bills and the like.

C. O. GUERNSEY:—I think that none of us should close our minds to any possible line of development that would permit us to use a greater percentage of the crude oil. I do not entirely agree with what Mr. Scott states. I have just made some rough calculations taken from figures given in Mr. Scott's tables. I may have made some assumptions that are not warranted but the figures I have are I think approximately correct. In one of the runs he reported 7 miles per gal. of oil with a total weight of, roughly, 5½ tons. I have assumed the road tractive effort required to be 60 lb. per ton, this being probably the requirement for an average country road, which I understand was the condition under which the truck was operated. Assuming 19,000 B.t.u. per lb. of oil burned, he is operating with an overall efficiency of somewhere around 11 per cent. That is neither particularly worse nor much better than we can get ordinarily from a gasoline engine.

Mr. Scott quotes some mileage figures for various trucks. I have no doubt that they are reasonably close to what is obtained in ordinary use in the hands of the average user, the trucks probably not being in the best of condition. However, Mr. Scott's figures are taken for experimental runs. I think for comparison we should give the gasoline engine the benefit of the same condition. It is easily possible with a conventional 2-ton truck without any special tuning up or anything of that sort to get from 7 to 9 miles per gal.

Undoubtedly, the steam engine does hold some possibilities. If Mr. Scott can develop a powerplant having an overall efficiency of some 28 per cent, as he mentions, we certainly should be very much interested. It seems to me that there is another line of development which possibly is being looked into under cover, but which has not been discussed to any great extent at the Society

meetings; that is, the constant-pressure type of engine, possibly a combination of the steam and the internal-combustion engine systems. A theoretical diagram of such an engine shows a thermal efficiency of from 41 to 48 per cent, depending upon the compression used and other conditions. Such a system would have also the advantage of operating at a better efficiency under part than under full-load conditions. This is another avenue that we should not overlook.

R. B. HALL:—Has Mr. Scott used double or triple-expansion engines in his steam truck or experimented with them?

MR. SCOTT:—We have not. The only type of engine we have ever used is a simple uniflow or semi-uniflow double-acting engine. We have got steam rates below 12 lb. per hp-hr. This equals any test result that I know of with engines anywhere near the size of ours, including triple-expansion engines. We did not feel justified in using anything more complicated than the engine we have.

THE CARE AND MAINTENANCE OF MOTOR TRUCKS

BY N. J. SMITH

THE object of this paper is to point out some of the difficulties of motor-truck maintenance and to suggest lines of improvement. The buyer and user of a motor truck sometimes experiences disappointments due to the lack of coordination between the engineering and sales departments of a truck company. The term "service" is often misunderstood by the purchaser and misrepresented by the salesman, which results in dissatisfied customers. Salesmen should have accurate information on the service policy of their company and on all guarantees which they are authorized to make.

After rehearsing many of the difficulties encountered in truck maintenance, the author discusses in some detail the needed improvements in truck design, passing then to details of maintenance practice and methods of handling repairs. The results stated are those of actual experience, which prove that it is more economical to expend money for the prevention of trouble than to apply the same amount and more toward repairing defects. [Printed in the April, 1921, issue of THE JOURNAL]

THE DISCUSSION

GEORGE T. BRIGGS:—I ask the following questions:

(1) How much mileage do you obtain from a set of final-drive chains, and what is the total maintenance cost during the period of that mileage?
(2) How often do you find it necessary to regrind cylinders and fit over-sized pistons?
(3) How often do you take up connecting-rod big-end bearings?
(4) How often do you regrind crankshafts?
(5) How often do you replace the friction disc of the clutch?

N. J. SMITH:—We get about 10,000 miles from a set of chains, depending upon the nature of the work; in hauling coal alone, we have run as high as 15,000 miles; if we are hauling stone or sand, the chains will not last as long.

The care that is given the engine determines the frequency of regrinding cylinders. We have engines in operation which have run over 30,000 miles without the cylinders being reground. Other cylinders have been reground after 15,000 miles. With good lubrication the engines will run years without regrinding the cylinders; lubrication is the big item.

The taking-up of connecting-rod bearings is another thing that is governed to a great extent by the care given the engine, although there are many things that have an influence on that. I would only be guessing at an average, as I did not come prepared with those figures. We have often run engines for 2 years without taking up the connecting-rod bearings; some have run longer than that.

I cannot say when it is necessary to regrind crankshafts. We have trucks more than 4 years old on which the crankshafts have not been reground. We found less than 0.002-in. wear on those shafts. That probably seems like an extreme statement. Lubrication is a main item there, also.

As to how often we find it necessary to replace the friction disc of the clutch, I have had trucks on which the clutch has burnt out within a month's time; other clutches have run years without repair. Unless a driver has an accident or gets stuck and burns a clutch up, we can say that it will last 1½ to 2 years; sometimes longer than that.

A. L. NELSON:—What kind of records are kept on fuel oil economy?

MR. SMITH:—We have a man who studies the amount of fuel and oil used. He spends all his time following the trucks on the street and in the garages. We are paying more attention to this subject than ever before. We are improving our fuel consumption.

F. J. SULLIVAN:—How many miles does one of these trucks make in a month?

MR. SMITH:—We estimate 1000 miles per month.

W. S. NATHAN:—Has Mr. Smith installed any apparatus to reclaim the crankcase oil? What does he do with the oil if he does not reclaim it?

MR. SMITH:—We have a filter in our main garage that we put the oil through. We take out all the dirt and grit and use the oil in our hoists. I have tried reclaimed oil in the crankcase recently, but only experimentally.

W. J. GRAMM:—I believe Mr. Smith mentioned that he included a 33⅓-per cent overload. Is it customary for the company to include that percentage of overload?

MR. SMITH:—Yes.

MR. GRAMM:—Is it possible to do that and maintain the trucks properly without serious trouble?

MR. SMITH:—I can give no statistics for or against it. We are doing it and believe we are successful. We cannot see wherein a truck is not keeping up to its standard as well with a 33⅓-per cent overload. We are watching the speed. We know that speed is more dangerous to the truck than overload. Speed is one thing that we keep away from.

H. M. RUGG:—How large a force of mechanics does Mr. Smith keep at work in the repair-shop? What methods are used to train or instruct them in the work?

MR. SMITH:—Our mechanical force is small and consists usually of men we take on and instruct. We teach them the business.

APRIL COUNCIL MEETING

THE meeting of the Council held in Detroit on April 25 was attended by President Beecroft, Past-President Vincent, First Vice-President Horning, Vice-Presidents Bachman, Crane and Johnston, Councilor Brush and Dr. H. C. Dickinson and O. C. Berry of the Research Committee.

Research Matters

The Research Committee had held a session just before the Council meeting and discussed thoroughly the matter of procedure of the Research Department of the Society authorized to be established at the meeting of the Council held on Feb. 3. It was understood that the work of the department, to be managed by a man of suitable engineering and scientific attainments, would include the correlation of present data from all available sources. Emphasis was placed on the advisability and great value of eliminating duplication of thought and expense in research by joint procedure through the Society, its resourcefulness bringing about the cooperation of many institutions and companies and the securing of desired results relatively quickly and accurately. It is understood that it would be impossible to replace with a central organization general research but it is felt that unnecessary duplication of effort can be gradually eliminated. A number of men starting from different points are much more likely to reach the goal sought. Some results of research conducted 20 years ago are not widely known and should be disseminated for general educational purposes. Work that has been done should not be done over again. It is the view of the Research Committee and the Council that united effort should be exerted on problems that baffle the ability of individuals proceeding separately. The main argument for united effort is that some important problems are not being solved; advance has been made in the vaporizing of fuels currently available but it is not clear that it has been conquered. More fundamental study should be conducted for the benefit of all. The work of individuals as such should not, of course, be interfered with, but joint work on the problems common to all will give the best results to the industry. The individual viewpoint is frequently too narrow. Bases for testing should be stipulated so that comparable results will be possible. That alone would compensate for the coordinative work contemplated.

It is not the intention that the Society shall itself conduct a laboratory but that it shall keep in touch with individual activities and collate and publish test results. Various developments in the industry must be guided along sanely determined lines. It is stated plausibly that in many instances money is wasted in improperly conducted tests and research work. Moreover, with the great duplication of work now prevalent, there is frequently not time available to solve completely any one problem, and there are many problems that are of general interest.

Clear distinction must be borne in mind between development work and research work. The work of the Society as such must stop with the discovery of facts and not extend to the application of them in design or reduction to patented form. The term "research" is used with lack of general understanding as to what research is. One suggested definition is that research is analyzing a problem and securing fundamental data to solve it. Routine tests are not research. Confusion results as to what research is, because research and experimental development go hand in hand.

The Research Department of the Society will confine itself to the collection and dissemination of fundamental information. Duplication of effort is necessary in the application of principles. There should be also intelligent duplication of research work. The human equation holds in research through the effect of unsuspected variables. The human mind is not big enough to assure that a set of test conditions determined by one man is adequate; something overlooked may amount to a fatal defect. On the other hand, mutual knowledge of the efforts of various people may stimulate better work by all of them.

The Society's Research Department will check the test results of different laboratories. The work of the department will be under the supervision of the Research Committee. No engineer will be criticized adversely for not giving information he considers it would be improper for him to give. The information disseminated by the Society will relate to methods only and not bear on commercial phases, such as "makes." The main purpose in mind is to meet the general need for assistance of a fundamental nature. To this end the facilities of many institutions are available.

It is expected that the Research Department will be in active operation within a few months. Its establishment constitutes a step of the first order of importance in the history of the Society and the plans for its work are accordingly being considered with great care.

Finance

The balance sheet as of March 31, 1921, showed that the net unexpended income for the first 6 months of the current fiscal year was $4,462.99. The income for the period was $125,686.55. A statement was submitted of income and expense for the first 6 months of this fiscal year, beginning Oct. 1, 1920, in comparison with the corresponding 6 months of the last fiscal year. This showed that the income for the first half of this fiscal year was $409.08 more and the expense $1,589.13 less than for the first half of the last fiscal year.

The market value on March 31 of the $105,000 par value of Government and railroad bonds owned by the Society was $97,521.50, as compared with $98,268.10 on Feb. 28. The total assets of the Society on March 31, 1921, were $210,773.95, with accounts payable of $11,056.37; the total assets comprise the general reserve of $130,028.52, the unexpended income accumulated during the last 10 years, and special reserves for distribution to income and expense items over the present fiscal year of $69,689.06.

Membership

Seventy-one applications for individual membership and 6 for student enrollment were approved.

The following were transferred from Associate to Member grade: George A. Gastineau and Dean E. Baskerville.

Eighty-two applications for membership were received during March, as compared with 86 for the same month of 1920. Two hundred and eighteen applications were received during January, February and March of this year, as compared with 241 during the same three months of 1920. On March 31 there were 5416 names on the rolls of the Society, including Affiliate Member Representatives and Enrolled Students, as compared with 4701 on the same day of 1920.

Standards Committee

The following additional appointments to the Standards Committee were made, with assignments as indicated:

F. C. Barton—Isolated Electric Lighting Plant Division
H. E. Brunner—Ball and Roller Bearings Division
L. F. Burger—Isolated Electric Lighting Plant Division
A. G. Carman—Non-Ferrous Metals Division
D. L. Colwell—Non-Ferrous Metals Division
V. A. Crosby—Iron and Steel Division
S. F. Evelyn—Electrical Equipment Division and Engine Division
A. W. Kinman—Non-Ferrous Metals Division
C. D. Ryder—Lighting Division
L. D. Simpkins—Non-Ferrous Metals Division
F. W. Slack—Parts and Fittings Division
G. W. Smith—Radiator Division
James A. White—Radiator Division

An Axle and Wheel Division of the Standards Committee was established with the personnel specified on page 606 of this issue of THE JOURNAL.

The most important work of this Division will relate to

consideration of standardization of wheel-hubs for passenger cars and motor trucks, a recommendation for Recommended Practice for front-wheel hubs for motor trucks having been submitted by the Truck Division at the meeting of the Standards Committee held on May 24. The jurisdiction of the Axle and Wheel Division will include also matters of standardization involved in axle and wheel elements, excepting tires and rims.

The following subjects were assigned to Divisions:

PARTS AND FITTINGS DIVISION

Shims
Water-Pipe Flanges

PASSENGER CAR BODY DIVISION

Beads for Wiring
Door Fit Clearances
Door-Handle Escutcheon-Plates
Door-Hinges
Drill Sizes for Wood Screws
Fender-Irons
Leather
Nickel-Plating
Plate Glass
Rolled Sections
Tee Moldings
Top Irons
Types of Bodies
Window Runways

SCREW-THREAD DIVISION

Rivets

STATIONARY ENGINE DIVISION

Babbitts
Connecting-Rods
Crankshafts
Governor Springs
Lubricators and Oil-Cups
Piston-Pins and Bushings
Piston-Rings
Spark-Plug Hoods
Water-Pot (Hopper) Capacity

TRACTOR DIVISON

Non-Freezing Solutions

TRANSMISSION DIVISION

Clutch-Bearing Oiling Mechanism

A. W. Copland was appointed to represent the Society on the American Engineering Standards Committee's Sectional Committee on Gears.

George A. Green was designated as the representative of the Society on the Advisory Board to the United States Government Interdepartmental Committee on Standardization of Petroleum Specifications.

SECTIONS

The Council had been considering since its February meeting the question of financial support of the Sections by the Society. In accordance with recommendations of the Sections Committee, it was decided at the April meeting not to change the amounts annually appropriated by the Society to the Sections, but to authorize the Sections in emergencies or in case of extraordinary expense to solicit donations from individuals and companies. The maximum amount to be accepted from any individual or company was fixed at $500 and the total amount to be so received by any Section during one year was set at $3,000. In the event of a Section accepting donations, the amounts and names of all donors are to be reported to the Council. It is not felt that the solicitation of funds in this way should be encouraged, but the Council is of the opinion that in case of unusual expense the Sections should be permitted to use their own good judgment in this connection within the limits stated.

OBITUARIES

BRUNO DAHL, works manager for A.-B. Abo Jernmanufaktur och Waggonfabrik O.-Y., Abo, Finland, died in November, 1920, of pneumonia, aged 36 years. He was born Nov. 3, 1885, at Helsingfors, Finland, and was graduated in 1911 from the Technical University of Finland with the degree of master of mechanical engineering.

From Sept. 1, 1905, to May 10, 1915, his practical experience was inclusive of machine-shop work, assembling and testing gasoline and Diesel marine engines and drafting for various foreign and domestic firms. He was chief draftsman for the Pittsburgh Model Engine Co. and engineer for the automotive department of the Standard Steel Car Co., both of Pittsburgh, from May, 1915, to about July 1, 1919, when he went abroad. His work at Abo consisted of the designing of engines and transmissions and specialization in the problems of the gasoline and kerosene internal-combustion engine. He was elected to Member grade in the Society, Dec. 10, 1919.

ROBERT J. DU BARRE, assistant manager of sales for the Geuder, Paeschke & Frey Co., Milwaukee, died April 20, 1921, aged 34 years. He was born Jan. 7, 1887, at St. Paul, Minn., and following his High School course attended the Milwaukee School of Enginering for 3 years.

From 1904 to 1908 he was a draftsman in the engineering department of the Wisconsin Telephone Co. and was chief draftsman for the company from 1908 to 1912.

For several years preceding September, 1912, he was in charge of the maintenance and operation of its motor-truck fleet. From Sept. 1, 1912, to 1915, he occupied an executive position relating to purchasing, motor sales and engineering, with the Falls Machine Co., Sheboygan Falls, Wis., and left this firm to form a connection with the Geuder, Paeschke & Frey Co. which he continued until his death.

He was held in high esteem by his friends and business associates, because of his attractive personality and on account of his engineering and business ability. He was elected to Associate Member grade in the Society, June 23, 1913, and transferred to Member grade Oct. 17, 1913.

HOWARD M. JOHNSON, manager of the rebuilt truck department of the Mack International Motor Truck Corporation, Los Angeles, Cal., died Feb. 25, 1921, aged 34 years. He was born June 29, 1887, in New York City and was educated at the Polytechnic Institute of Brooklyn and Columbia University.

In 1910 he was employed by the Locomobile Co. at Boston as a machinist and salesman. He severed this connection May 10, 1917, to enter the United States Navy as a chief machinist and gas-engine specialist, being assigned later to Submarine Chaser No. 417 as its commanding officer and remaining in the naval service until Jan. 13, 1919. For a short period following this he was marine machinist of the Southwestern Shipbuilding Co., San Pedro, Cal., and from June, 1919, to December, 1920, was a transportation engineer detailed on fleet advisory work in motor-truck transportation for Harold L. Arnold, Los Angeles, Cal., leaving this position to go with the Mack International Motor Truck Corporation.

During his career he collected considerable engineering data on automobile and marine gas engines, in connection with his practical machine-shop experience and naval engineering test work. He was elected to Associate Member grade in the Society, Nov. 22, 1920.

Dr. EDWARD B. ROSA, chief physicist of the Bureau of Standards, died suddenly in his office at Washington on May 17. He was born in Rogersville, N. Y., Oct. 4, 1861. His education included a course at Wesleyan University, from which he was graduated in 1886 with the degree of bachelor of science, and post graduate work at Johns Hopkins University from which he received the degree of doctor of philosophy in 1891. After serving as professor of physics at Wesleyan from 1891 to 1902, he became physicist at the Bureau of Standards. The degree of doctor of science was conferred upon him in 1906 by Wesleyan University. In 1910 he became chief physicist of the Bureau.

Dr. Rosa did notable work in the scientific field, particularly in electrical research. Subsequently to the entry of this country into the war he developed a number of scientific instruments which were of great value to the American Expeditionary Force. He also invented industrial plant safety devices and was active in the establishment of the aircraft safety code.

ACTIVITIES OF THE SECTIONS

RECENT elections by the Sections have resulted in the selection of the following members to serve on the Annual Nominating Committee of the Society for 1922:

	Member	*Alternate*
Boston	L. W. Rosenthal	Ira D. Shaw
Buffalo	H. R. Corse	J. T. R. Bell
Cleveland	A. E. Jackman	C. S. Pelton
Dayton	Thomas Midgley, Jr.	John H. Hunt
Detroit	Russell Huff	C. C. Hinkley
Indiana	W. G. Wall	Mark A. Smith
Metropolitan	Harold W. Slauson	M. C. Horine
Mid-West	Foree Bain	William O. Olson
Minneapolis	A. W. Scarratt	None
Pennsylvania	F. M. Germane	Edward L. Clark
Washington	H. C. Dickinson	W. S. James

The alternate in each case is authorized to act only in the absence of the first designated committeeman. In addition to these men there are elected at the business session of the Semi-Annual Meeting three members of the Society at large who with the 11 representatives of the Sections constitute the Committee. The President and the Secretary of the Society are ex-officio members of the Committee, but it has not been the custom for them to vote.

PROPOSED FALL MEETINGS

An earnest effort will be made to improve the quality of papers and to increase the attendance at Section meetings by planning the schedules a full year in advance. This has proved successful in the case of the Minneapolis Section and with the sections of other engineering societies. Arrangements for papers will be made well in advance of their presentation and so far as possible preprints made so that members of the Sections may have time to read the papers in advance of their presentation. Under these circumstances the authors can give at the meetings short abstracts of their papers, allowing more time for discussion. More members should be able to take part in the discussions and the character of the discussions should also be improved since it will be possible for the members to be prepared to discuss the papers instead of being compelled to make extemporaneous remarks.

The Mid-West Section has already outlined a program for six sessions on the fundamentals of internal-combustion engines, covering the laws of thermodynamics, the principles of carburetion, combustion phenomena and thermal and mechanical losses.

RECENT MEETINGS

H. H. Platt spoke on May 6 before the Washington Section at the Cosmos Club on the design of piston-rings. He showed mathematically and by test results that leakage through the gap of a piston-ring is of slight importance compared with the leakage around the wall of the cylinder. Engineers of various piston-ring manufacturers were present and entered into a lively discussion on the advantages and disadvantages of the different methods of manufacture. Moving pictures were shown and an interesting description given by John A. Allen of the method of extinguishing difficult fires by a chemical foam.

The Indiana Section meeting of May 5 was taken up largely with the perfecting of plans for the Section's participation in the program of the Summer Meeting. Due to the fact that the Semi-Annual Meeting was held this year in Indiana, the Section spent considerable time and effort in contributing to its success by arranging an Indiana Night program. Those who were at the meeting will appreciate the work done by the Indiana members.

The Mid-West Section gave a party on May 13 and in recognition of the desire of the members to conserve their financial resources for the attractions at the Summer Meeting, the members and guests ate, smoked, and were entertained at a price which was "back to normalcy." Over 60 were present.

The Minneapolis Section held its concluding spring meeting on May 4. William Kidder spoke on airplane patrol, Russell Greer talked on Trucking in the Twin Cities, and Phil Overman gave an account of the use of tractors in the logging woods.

The Dayton Section fittingly concluded its excellent first season's program with a talk by H. L. Horning.

Car-theft prevention and its relation to automobile insurance received the attention of the Metropolitan Section at its meeting on May 19. The Cleveland Section on the following night considered the subject of automobile insurance in general. Figures recently quoted by one of the insurance companies indicate that in many instances full insurance costs annually more than one-quarter of the value of the car. Practically all the losses covered by insurance are preventable. A fuller account of these important meetings will appear in a subsequent issue of THE JOURNAL.

TRANSPORTATION IN DIFFERENT COUNTRIES

TRAFFIC in new countries always follows the waterways. When the pioneers begin to branch from these lines of portage, then begins the development of the highways. There is no more fascinating and interesting subject in the history of civilization than the development and use of highways. The framers of the Constitution of the United States recognized that transportation and communication were of primary and fundamental importance, if the union which they were creating was to continue, and made provision for the building of highways known as post roads.

Up to the time of the advent of the railroads there was in this country a notable development of the highways and there still remain some of these, such as the post road connecting Boston and New York, the National Pike from Baltimore to the Ohio River, the Philadelphia-Pittsburgh Pike and others. Over these highways there flowed from the East over the Allegheny Mountains an enormous amount of traffic, and those sections of the country which were reached by these highways were naturally the earliest to develop.

Railroads were looked upon as substitutes for these highways and for several generations the country lost interest in the development of a national highway system, but the advent of the automobile provided a new means of transportation for passengers and freight and there immediately arose an insistent demand for better roads.

The cost of transportation in different countries in 1902 is given in the following table:

Countries	Per ton-mile	Wages per day
China	$0.1000	$0.10
Japan	0.0500	0.23
Russia	0.0220	0.34
Italy	0.0240	0.26
Austria	0.0225	0.50
Germany	0.0150	0.90
France	0.0190	0.80
England	0.0260	1.04
United States	0.0069	2.60

—F. L. Bishop.

CURRENT STANDARDIZATION WORK

THE eight Division meetings held during April and the Standards Committee Meeting on May 24 brought to a close the active work of the Standards Committee for the first half of 1921. Reports of 10 Divisions covering 26 recommendations were submitted at the Standards Committee Meeting, copies of which were sent to the Society members in pamphlet form prior to the meeting. The report of the Standards Committee as approved by the Council and at the Society Meeting will be published in the July issue of THE JOURNAL, together with the discussion.

A large amount of Division and Subdivision work is, however, in progress which will be carried on during the coming months although it is expected that the vacation season will retard the work somewhat.

AXLE AND WHEEL DIVISION

An Axle and Wheel Division has been appointed by the Council to consider the standardization of axles and wheels and parts germane thereto. G. W. Dunham has accepted the chairmanship, the other members appointed being C. C. Carlton, vice-chairman, T. V. Buckwalter, R. J. Burrows, J. Coapman, C. S. Dahlquist, F. W. Gurney, G. L. Lavery, A. M. Laycock, C. T. Myers, A. L. Putnam, J. G. Swain, G. J. Thomas and H. Vanderbeck. This newly formed Division will cooperate with the Truck Division on the wheel-hub standardization work which the Truck Division has carried on during the last two years, having submitted a report on motor-truck front hubs at the Semi-Annual Meeting of the Standards Committee. The eventual standard, will, if feasible, include hub dimensions for passenger-car front-axle hubs and passenger-car and motor-truck rear-axle hubs. Other subjects before the Division are brake-drums, differential gears, emergency rim clamps and metal wheel felloes. A Subdivision consisting of R. J. Burrows, chairman, H. S. Jandus and representatives of pressed steel parts manufacturers has been appointed to consider the subject of brake-drums. A tentative report drawn up by the Truck Division during 1920 will be used as a basis for the Subdivision work.

ELECTRICAL EQUIPMENT DIVISION

A subdivision has been appointed to consider the subjects of flexible steel and non-metallic conduit, consisting of B. M. Leece, chairman, W. S. Haggott, Ernest Wooler and representatives of the National Metal Molding Co. and the American Circular Loom Co. The work of the Subdivision will be to bring the present S. A. E. Standard for flexible steel conduit into accord with present insulated-cable practice and to formulate recommendations for non-metallic conduit as a large amount of circular loom is now being used for automobile wiring.

The Division has under consideration the desirability of standardizing the distance from the end of the coupling tongue to the end of the distributor body for the Type *B* S. A. E. Standard timer-distributor, page B16, S. A. E. HANDBOOK. Final action will be based on comments received in answer to a general letter that will be sent out shortly

The Division has been requested to consider the desirability of shortening the present shaft length of the generator flange mounting to permit decreasing the overall distance from the face of the generator flange to the inside of the gearcase cover as in some applications the gearcase cover interferes with the fan. As the present standard is widely used, final action will be based on comments received through circularization.

The Division has approved the recommendation of the S. A. E. Patent Committee that the illustration of the present S. A. E. Recommended Practice for starting-motor barrel mounting, page B20, S. A. E. HANDBOOK, be redrawn so as to indicate only the actual dimensions standardized. As it is considered good engineering practice to cover tractor and farm engine spark-plugs with non-metallic molded hoods to make them waterproof, when the engine is not protected by a hood or other housing, the Division has, at the request of the Stationary Engine Division, appointed a Subdivision to obtain data and prepare a report based on present practice.

A Subdivision has been appointed to consider the further standardization of magneto mountings with special reference to mountings for stationary-engine, isolated-electric-lighting-plant and tractor magnetos. Interchangeability of magnetos is considered one of the important problems before these industries at the present time. Members of the Subdivision are F. W. Andrew, chairman, A. D. T. Libby, J. M. Edwards, representing the Stationary Engine Division, W. F. Bogerd, representing the Tractor Division and F. L. Tubbs, representing the Isolated Electric Lighting Plant Division.

ENGINE DIVISION

The Division has discussed in detail the advisability of consolidating the flange dimensions of the ½ and ⅝-in and the ¾ and ⅞-in. nominal carbureter sizes, although retaining the same actual inside diameters as at present. As this modification will affect the design of carbureters and manifolds, the final report of the Division will be based on the results of circularizing.

The Subdivision on Engine Testing Forms is studying the present standard engine testing forms with a view to extending them to permit adding data on lubricants and will also incorporate several suggestions which have been received in connection with the present forms.

The Subdivision on Fan Belts and Pulleys recently appointed consists of Louis Schwitzer, chairman, C. E. Jacobs, H. A. Weaver, G. A. White and K. F. Walker. At the meeting of the Engine Division on April 18 held jointly with the members of the Subdivision on Fan Belts and Pulleys it was recommended tentatively that the included angle for V-belts, both rubber and leather, and pulleys should be 40 deg. This angle was recommended after a careful review of V-belt practice which varies from 28 to 45 deg., and as it was understood that for the smaller angles the wear on the belts is excessive and that for the larger angles the heavier belts cause excessive slipping at high speed owing to their greater weight and the resulting centrifugal force.

It is proposed to revise the present S. A. E. Standard for fan belts and pulleys by omitting the ¾ and the 1¾-in. widths, as they are used to a very limited extent, and adding the 2½ and 3-in. widths, which are intended to meet the requirements for heavy truck and tractor engine installations.

As it is considered that standardization of the fan driving pulley diameters would be of material assistance in designing and installing fan equipment, the tentative proposal given in the following table was adopted

PROPOSED FAN DRIVING PULLEY DIAMETERS

Number of Cylinders	Ratio of Fan to Engine Speed	Pulley Diameter, in.
6	1	3, 3½, 4
4	1½	5½, 6 , 6½

Radius of crown to be 6½ in. for all pulley sizes.

Pulley diameters vary considerably in practice and their standardization will permit the fan manufacturers to layout the driven pulley for practically any fan speed desired, and it will facilitate also the determination of the diameter of the driven pulley for various fan installations.

The tentative recommendations applying to fan belts and pulleys and fan hubs will be circularized among the manufacturers interested for comment before final action is taken by the Division

The following recommendation was approved by the Standards Committee at its January meeting:

> Mufflers shall vary in diameter and in length by even inches and shall be supported by hands extending around the circumference.

Owing to the large number of negative votes cast against the adoption of this proposal by Members of the Society, the Council referred the recommendation back to the Engine Division for further consideration. A Subdivision consisting of M. J. Steele, chairman, R. J. DuBarre, Virgil Oldberg and Captain Seig has therefore been appointed to review the recommendation. The Subdivision will consider the suggestion to standardize muffler capacity with respect to piston displacement, as well as the standardization of the outside diameters of the exhaust and muffler outlet-pipes, the outside diameters and lengths of mufflers and the location and size of the through-bolts for assembling them.

Non-Ferrous Metals Division

The subjects awaiting consideration by the Non-Ferrous Metals Division have been assigned to Subdivisions on Aluminum Alloys, Wrought Brasses and Bronzes. Die-Casting Alloys and Miscellaneous Non-Ferrous Metal Alloys, the Chairmen of which are Zay Jeffries, W. B. Price, Charles Pack and H. C. Mougey respectively. Subjects under consideration include brazing brasses, hard and soft solders, aluminum sheets, rod and tubing, Tobin-bronze tubing, brass and bronze spring-wire, brass forging-rod, die-casting alloys and babbitt.

Parts and Fittings Division

The Division has given considerable attention to the feasibility of formulating specifications for testing felt, but has come to the conclusion that it is impracticable to do so. The subject has therefore been tabled indefinitely.

The original tentative recommendation of the Subdivision on Horn Mountings specified an outside mounting on the running-board of the car, an engine mounting for which two studs were considered sufficient, with an alternate bracket which would permit mounting the horn under the head of one of the cylinder cap studs, and a dash mounting which is being used at the present time by a few companies. As it was the consensus of opinion that it would be difficult to specify a location on the cylinder block that would permit of sufficient clearance on all makes of cars, the subject has been tabled indefinitely.

C. W. Spicer, who was assigned the work of formulating specifications for taper and straight serrated-shaft fittings, submitted a tentative recommendation for straight serrated-shaft fittings at the April 19 meeting of the Division. The recommendation was not based on theoretical dimensions but upon the dimensions working from the pitch-line in somewhat the way screw-threads are dimensioned. A recommendation for the taper serrated-shaft fittings is being worked out along the same principle. The two proposals will be referred to manufacturers for comment before final action is taken by the Division.

A Subdivision report has been submitted by E. W. Hart covering revisions of the present S. A. E. Standard for lock washers, page C5, S. A. E. Handbook. Three series of lock washers are recommended, "Standard," "Special Light" and "Special Heavy," for both S. A. E. Standard bolts and standard machine-screws with either round or fillister heads. The report will be circularized among the automobile and parts manufacturers and comments received referred to members of the Parts and Fittings Division for consideration.

The Transmission Division has recommended that the present S. A. E. Standard for taper fittings with plain or slotted nuts be revised by the addition of a note reading, "The center-line of the cotter-pin hole shall be 90 deg. from the position of the keyway as shown on the drawing," because many times question arises as to the location of the cotter-pin hole with respect to the position of the keyway.

The Division is working on the standardization of flexible discs for magneto-couplings and universal-joints. Although flexible-disc universal-joints are considered to be in a stage of evolution, it is thought that standardization will do much to decrease the large number of mold sizes necessary at the present time and facilitate replacements and interchangeability.

PRINCIPLES UNDERLYING ELECTRICAL IGNITION

(*Concluded from page* 576)

Professor Bailey:—It depends upon the condition of the electromotive force of the coil and other things. In general, if a coil gives a high enough electromotive force, a somewhat wider gap will probably give more energy. Whether that energy is more effective or not, I do not know. I have stated that I believe that if the gap is widened and the energy distributed over a larger volume, it has not much more power, if any. On the other hand, making the gap too short will interfere more or less with the ignition. I understand that a gap can be so short that there will be no ignition because there is not enough spark.

E. H. Vincent:—Why do ordinary commercial generators have a greater output cold than warm? Is it caused by resistance?

Professor Bailey:—Yes, the resistance of the generator increases very much as it heats up. The rise of temperature is in the neighborhood of perhaps 40 deg. cent. (104 deg. fahr.). The generator becomes hotter and the resistance of copper wire changes 0.4 per cent to the degree. That means a change of about 16 per cent, which is enough to affect the output very materially. It cuts down the shunt current about 14 per cent and at the same time increases the armature resistance 16 per cent; it is harder to get the current through and so there is a very decided decrease of it.

Mr. Barthel:—Is it possible to proportion the winding of the coil so that it will be in exact proportion with the deflection of the spring or vibrator, so that practically synchronous action is obtained? The consensus of opinion seems to be that it is not possible to accomplish that, although one person claimed that he had accomplished it; in other words, by putting additional windings on the core, or the coil, to get an action so that practically the pull will be proportional to the spring deflection.

Professor Bailey:—I think it would be extremely difficult, if not impossible, to do that.

Mr. Barthel:—That seemed to be the consensus of opinion of all the electrical engineers and the coil-manufacturers, and yet it was claimed that this result was accomplished.

Professor Bailey:—The pull would run up very rapidly as the iron armature approached the core, and the spring tension would not run up so rapidly.

Mr. Barthel:—I can understand how an approximation of it would be possible.

Professor Bailey:—I do not see that it could be done, except approximately, as you say, because the laws are more or less radically different. With a solenoid it would not be very difficult to do it. There is a considerable range wherein the pull is represented by a straight line and it might be possible to do it by a combination.

Applicants *Qualified*

The following applicants have qualified for admission to the Society between April 9 and May 10, 1921. The various grades of membership are indicated by (M) Member; (A) Associate Member; (J) Junior; (Aff) Affiliate; (S M) Service Member; (F M) Foreign Member; (E S) Enrolled Student.

ALEXON, JOHN M. (E S) 106 First Street, South, *Virginia, Minn.*

APOR, EMIL L. (J) Cotton, Neill & Co., *Honolulu, T. H.*, (mail) 1278 Punchbowl Street.

ARMINGTON, A. P. (M) superintendent and tractor engineer, Euclid Crane & Hoist Co., *Euclid, Ohio.*

AUCOCK, HERBERT (A) proprietor, Herbert Aucock Co., 185 Columbus Avenue, *Boston.*

BLAKE, E. A. (J) in charge of experimental department, Transport Truck Co., *Mount Pleasant, Mich.*

BRADY, L. J. (A) assistant manager, Nash Sales Co., 2000 South Michigan Avenue, *Chicago.*

BROWN, GORDON (M) engineer, Condensite Co. of America, *Bloomfield, N. J.*, (mail) 79 North Mountain Avenue.

BRYANT, WILLIAM L. (M) president, Bryant Chucking Grinder Co., *Springfield, Vt.*

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BUTTNER, EDGAR LOUIS (E S) student, University of California, *Berkeley, Cal.*, (mail) 1522 Walnut Street.

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CHAILLIEY, GEORGE A. (A) American manager, Panhard & Levassor, 19 Avenue de Troy, *Paris, France*, (mail) 24 rue Vignon.

COBB, E. E. (A) manager of sales and service, United States Malleable Iron Co., *Toledo.*

COLE, W. F. (A) chief inspector, automobile body department, Osgood Bradley Car Co., *Worcester, Mass.*, (mail) 30 Rockdale Street.

COLEMAN, CHARLES H. (M) assistant mechanical engineer, power plant section, Bureau of Standards, *Washington*, (mail) 1329 H Street, Northwest.

DALEY, FRANK R. L. (A) chief inspector, Northway Motors Corporation, Natick, Mass., (mail) 183 West Central Street, *West Natick, Mass.*

DAVIS, HOWARD LA MONTE (A) sales engineer, Connecticut Telephone & Electric Co., Meriden, Conn., (mail) 1734 Ridge Avenue, *Evanston, Ill.*

DELAVAL-CROW, THOMAS CLIVE (M) chief engineer, New Departure Mfg. Co., *Bristol, Conn.*, (mail) 132 Stearns Street.

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GAGE, OSCAR THOMAS (A) assistant general foreman, Sheridan Motor Car Co., *Muncie, Ind.*, (mail) 1420 West Ninth Street.

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HOOD, CLIFFORD F. (A) superintendent, electric cable works, American Steel & Wire Co., *Worcester, Mass.* (mail) 738 Main Street.

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JONTZ, G. F. (M) chief inspector, tractor works, Moline Plow Co., *Rock Island, Ill.*, (mail) 806 44th Street.

KAZEY, ARTHUR R. (M) assistant chief engineer, Ross Gear & Tool Co., *Lafayette, Ind.*, (mail) 806 Cincinnati Street.

KELLEY, E. A. (A) sales representative, Splitdorf Electrical Co., Newark, N. J., (mail) 1295 Woodward Avenue, *Detroit.*

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LAGUIRE, RAYMOND F. (J.) laboratory assistant, Joseph Tracy, New York City, (mail) 89 Prospect Place, *Rutherford, N. J.*

LAZARNICK, NATHAN (A) proprietor, Commercial Photography, 246 West 42nd Street, *New York City.*

LEET, ALBERT B. (M) chief draftsman, Rockford Drilling Machine Co., *Rockford, Ill.*, (mail) 1317 North Main Street.

LINCOLN, WILLIS C. (A) engineer, National Railway Appliance Co., New York City (mail) 70 John Street, *Belleville, N. J.*

LINEK, JOSEPH, JR. (J) foreman, J. Linek, *Maspeth, N. Y.*, (mail) 5 Elm Street.

LINNEY, WILLIAM A. (A) foreman, dynamics laboratory, Aluminum Manufactures, Inc., *Cleveland*, (mail) 2140 Broadview Road.

MCKENNA, A. W. (A) superintendent, Osgood Bradley Car Co., *Worcester, Mass.*, (mail) 465 Park Avenue.

MCMAHON, JAMES J. (J) in charge of engineering, Mercury Motors Corporation, 5929 Baum Boulevard, *Pittsburgh.*

MALOON, EARL B. (J) draftsman, C. L. Best Gas Tractor Co., San Leandro, Cal., (mail) 2587 35th Avenue, *Oakland, Cal.*

MIDGLEY, ALBERT HENRY (F M) chief engineer and advisor, C. A. Vandewell & Co., Ltd., Acton, London, West, (mail) Fairfield, Harefield Road, *Uxbridge, England.*

NEWTON, M. H. (A) advertising manager, White Co., *Cleveland*, (mail) 6611 Euclid Avenue.

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OUTCALT, WILLIAM J. (J) head of standard parts department, General Motors Corporation, *Detroit*, (mail) 6003 McClellan Avenue.

OVERMAN, PHIL N. (A) sales engineer, Hyatt Roller Bearing Co., Chicago, (mail) 10 South 10th Street, *Minneapolis.*

PITTMAN, KNOWLES (A) sales manager, Electric Steel Co., Chicago, (mail) 882 Elm Street, *Winnetka, Ill.*

POPPE, PETER A. (F M) technical director, White & Poppe, Ltd., *Coventry, England*, (mail) Logna, Warwick Avenue, Earlston.

PRATT, JAMES M. (A) assistant to general manager, Northway Motors Corporation, *Natick, Mass.* (mail) 81 Speen Street.

REDFIELD, C. S. (M) manager, development department, Dunlap Tire & Rubber Corporation of America, *Buffalo, N. Y.* (mail) 48 Irving Place.

RUTLEDGE, C. B. (A) proprietor and manager, Auto Equipment Service Co., *Memphis, Tenn.*, (mail) 27 North Belvedere Boulevard.

SANDERS, WILLIAM E. (A) assistant engineer and general superintendent, Standard Automotive Corporation, *Mooresville, Ind.*

SEYMOUR, GLEN F. (M) trouble investigator and layout man, Cleveland Automobile Co., *Cleveland* (mail) Hotel Regent.

SAUER, HERBERT F. (A) branch manager, Electric Storage Battery Co., Philadelphia, (mail) 2325 Chester Avenue, *Cleveland.*

SHIDLE, NORMAN G. (A) editorial staff, *Automotive Industries, New York City*, (mail) 880 West 180th Street.

SNYDER, FLOYD E. (A) chief inspector, Stutz Motor Car Co., *Indianapolis*, (mail) 1301 Parker Avenue.

STEADMAN, CLAUDE A. (J) chassis and motor layout, C. H. Wills & Co. *Marysville, Mich.* (mail) Box 41.

STEWART, JAMES L. (A) vice-president and general manager, Thomart Motor Co., *Akron, Ohio.*

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THOMS, LOUIS (M) engineer, truck division, Advance-Rumely Co., *Battle Creek, Mich.*

VANCIL, E. D. (J) designer, Garford Motor Truck Co., *Lima, Ohio*, (mail) 468 East Pearl Street.

WALKER, GILBERT DUNSTAN (M) production manager and engineer, Nofalt Motor Products Co., Inc., Holyoke, Mass., (mail) 14 Charter Oak Avenue, *Hartford, Conn.*

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WEINSTEIN, HARRY (E S) student, Pratt Institute, *Brooklyn, N. Y.*, (mail) 1764 Bergen Street.

WEISSINGER, HORACE L. (M) superintendent, automobile body department, Osgood Bradley Car Co., *Worcester, Mass.*, (mail) 614 West Boylston Street.

WELLS, D. W. (M) vice-president and general manager, Electric Steel & Forge Co., Cleveland, (mail) 1205 Overlook Road, *Lakewood, Ohio.*

WHITE, EARL A. (M) technical editor, *Farm Implement News*, Masonic Temple, *Chicago.*

WILLIAMS, CHESTER P. (A) sales engineer, Northway Motors Sales Co., Boston, (mail) 33 Florence Street, *Natick, Mass.*

WILLIAMS, J. J. (M) general production superintendent, Federal Rubber Co., Cudahy, Wis., (mail) Apartment 611, 203 Juneau Avenue, *Milwaukee.*

Applicants *for* Membership

The applications for membership received between April 23 and May 19, 1921, are given below. The members of the Society are urged to send any pertinent information with regard to those listed which the Council should have for consideration prior to their election. It is requested that such communications from members be sent promptly.

ALLEN, GEORGE B., chief engineer, Liberty Motor Car Co., *Detroit.*

ANDERSON, A. E., garage foreman, Standard Oil Co., *Spokane, Wash.*

BARRETT, FRANK C., designer, Southern Motor Corporation, Ltd., *Houston, Tex.*

BARRETT, W. F., vice-president, Prest-O-Lite Co., Inc., *New York City.*

BARTLETT, LINTON G., vice-president and chief engineer, O'Connell Motor Truck Co., *Waukegan, Ill.*

BEAUDRY, PIERRE, student, Massachusetts Institute of Technology, *Cambridge, Mass.*

BLACK, CHARLES F., production manager, Osgood Bradley Car Co., *Worcester, Mass.*

BLACKMORE, LLOYD, patent attorney, General Motors Corporation, *Detroit.*

BLAIR, ROBERT, aeronautical engineer, *Elgin, Ill.*

BLUM, LOUIS E., JR., machine designer, Splitdorf Electrical Co., *Newark, N. J.*

BRADLEY, JOHN E., president, Osgood Bradley Car Co., *Worcester, Mass.*

BRADLEY, JOHN J., JR., chief follow man for factory, Continental Motors Corporation, *Detroit.*

BREWER, JOHN W., manager pricing department, International Motor Co., *New York City.*

BROPHY, J. W., assistant production superintendent, Remy Electric Division, General Motors Corporation, *Anderson, Ind.*

BUCHEN, WALTHER, advertising executive, J. Walter Thompson Co., *Chicago.*

BUXTON, H. B., merchant, Suipacha 602, *Buenos Aires, Argentine, South America.*

CARPENTER, MANSON C., sales engineer, Holley Carburetor Co., *Detroit.*

CARR, MOSES FRANCIS, assistant general manager, Carr Fastener Co., *Cambridge, Mass.*

CHASE, EUGENE P., assistant parts manager, Locomobile Co. of America, *Bridgeport, Conn.*

DARNELL, REX C., assistant chief engineer, Northway Motor & Mfg. Co., *Detroit.*

DEL PRADO, ALBERT, mechanic, Franclin Car Co., *Jersey City, N. J.*

DILGER, FRANK P., president, Checker Taxi Co., *Chicago.*

DODSHON, FRED G., by-products manager, General Motors Corporation, *Detroit.*

DONAHUE, F. M., student, International Correspondence Schools, *Scranton, Pa.*

DOYLE, JOSEPH A., sales and service department, Stromberg Motor Devices Co., *Chicago.*

DWYER, ROBERT E., director of motor buses, Commissioners of Lincoln Park, *Chicago.*

EDELEN, JAMES L., engineering department, Moon Motor Car Co., *St. Louis.*

FEEMSTER, DAVID R., assistant chief engineer, Bock Bearing Co., *Toledo.*

FORD, FRED H., manager of roadlighter department, C. A. Shaler Co., *Waupun, Wis.*

GARDINER, A. W., secretary, Trimming Supply Co., *Cleveland.*

GAUTHIER, EDWARD, mechanical draftsman, Holt Mfg. Co., *Stockton, Cal.*

GIBSON, ALLEN W., special representative, Prest-O-Lite Co., Inc., *New York City.*

GINSBERG, SAMUEL, partner, Ginsberg Motor Co., *Montreal, Canada.*

GOLDBERGER, ERNEST, tractor designer, Detroit Pressed Steel Co., *Detroit.*

GOSSLING, W. E., storage battery engineer, Prest-O-Lite Co., *New York City.*

GRUENBERG, WALTER H., student, Tri-State College, *Angola, Ind.*

HANSON, WALTER M., sales engineer, Geuder Paeschke & Frey Co., *Milwaukee, Wis.*

HARMON, C. O., sales engineer, Cleveland Engineering Laboratories, *Cleveland.*

HASTINGS, WARREN B., editor, Ontario Motor League, *Toronto, Canada.*

HEWITT, CLARENCE C., special factory representative, Tide Water Oil Sales Corporation, *Detroit.*

HOOVEN, ALBERT M., secretary and treasurer, Meteor Motors Corporation, *Philadelphia, Pa.*

HOWELL, HORACE L., manager of research, National Railway Appliance Co., *New York City.*

HUENING, C. L., assistant engineering inspector, Mitchell Motors Co., Inc., *Racine, Wis.*

HULBERT, L. G., metallurgist, Locomobile Co. of America, *Bridgeport, Conn.*

HULL, NAT. D., manager, Automatic Visible Pump Co., *Memphis, Tenn.*

JOHNSON, CHARLES B., general sales manager, Penberthy Injector Co., *Detroit, Mich.*

KALTWASSER, C. M., treasurer and general manager, Salisbury Axle Co., *Jamestown, N. Y.*

KEITH, EBEN F. S., vice-president, Osgood Bradley Car Co., *Worcester, Mass.*

KERSHNER, VIRGIL H., engineer, Oklahoma Gas & Electric Co., *Oklahoma City, Okla.*

KIMBALL, EARL W., vice-president, Ostendorf Motor Car Corporation, *Buffalo, N. Y.*

KINGSTON, CHARLES T., manager, John Brennan & Co., *Detroit.*

KOPPER, FREDERICK, JR., mechanical engineer, Bureau of Standards, *Washington.*

LANSING, RAYMOND P., chief engineer, Bijur Motor Appliance Co., *Hoboken, N. J.*

LARKIN, WALTER P., superintendent, jobbing division, Bock Bearing Co., *Toledo.*

LAUGHLIN, S. L., chief engineer, Peters Machine & Mfg. Co., *Cleveland.*

LEE, ROY E., chief draftsman, Russel Motor Axle Co., *Detroit.*

LINDSAY, H. O., chief engineer, department of internal-combustion engines, Pure Oil Co., *Minneapolis.*

LOCKWOOD, F. R., chief engineer, A. J. Detlaff Co., Inc., *Detroit.*

LOLLEY, WILLIAM H., export manager, Standard Parts Co., *Cleveland.*

LOVE, HORACE, Eastern sales manager, Parish Mfg. Corporation, *Reading, Pa.*

LYDECKER, J. M., engineer, Asch & Co., *New York City.*

MCALPIN, KENNETH, vice-president and general manager, Motor Products & Sales Co., *Seattle, Wash.*

MACDONALD, LACHLAN M., vice-president and general manager, Bryan Pattern & Machine Co., *Bryan, Ohio.*

MARKIN, MORRIS M., president, Markin Auto Body Corporation, *Chicago.*

MILLER, EDWARD J., chief draftsman, Allen Motor Co., *Columbus, Ohio.*

MIXSON, ROBERT E., motor mechanic inspector, Langley Memorial Aeronautical Laboratory, *Hampton, Va.*

MOORE, WHITLEY B., sales engineer, Timken Roller Bearing Co., *San Francisco.*

MUELLER, MAX M., superintendent, steering gear department, Borg & Beck Co., *Chicago.*

MUHLON, EDWARD, experimenting and testing on engines, H. D. Motors Corporation, *New York City.*

MURRAY, MAJOR MAXWELL, office, Chief of Field Artillery, *Washington.*

MURRAY, ROBERT R., mechanical superintendent, Provincial Highway Board, *Halifax, Nova Scotia.*

NAIDEN, JAMES H., director of laboratories, Prest-O-Lite Co., Inc., *Indianapolis.*

NATIONAL STEEL CAR CORPORATION, LTD., *Hamilton, Ont., Canada.*

NEIGH, JOSEPH R., director of service, Bessemer Motor Truck Co., *Grove City, Pa.*

NIELSON, MORITZ, mechanical engineer, Elgin Motor Car Corporation, *Argo, Ill.*

NORDSTRUM, G. W., secretary and treasurer, Aetna Ball Bearing Mfg. Co., *Chicago.*

NULL, JOSEPH F., general manager, Manufacturing Engineering Service, *Detroit.*

OBUCHOWSKI, ANTHONY, draftsman, Jaxon Steel Products, *Jackson, Mich.*

PENGILLY, H. EUGENE, mechanical engineer, motor carriage section, Ordnance Department, *Washington.*

PIERCE, J. OTIS, sales manager, Brown-Lipe Gear Co., *Syracuse, N. Y.*

PIERSON, LISLE A., service manager, Mack Motor Truck Co., *Hartford, Conn.*

POWERS, HARRY H., machine foreman, Remy Electric Division, General Motors Corporation, *Anderson, Ind.*

PROSPERI, A. G., service manager, Southern Oakland Co., *Atlanta, Ga.*

RAMSAY, LLOYD M., assistant superintendent of motor equipment, Charlotte branch, Standard Oil Co. of N. J., *Charlotte, N. C.*

REITER, R. H., manager, Perfection Piston Ring Co., *Ravena, Ohio.*

ROBINSON, L. G., sales and advertising manager, Bantam Ball Bearing Co., *Bantam, Conn.*

ROGERS, JAMES B., experimental engineer, Joy Ball Bearing Co., *Chicago.*

REAM, FRED H., inventor and developer of the National Snubber, National Steel Products Co., *Dayton, Ohio.*

SAWYER, ALBERT F., chief engineer, American Motors Export Co., *Jacksonville, Fla.*

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SCHUMANN, FRANK A., master mechanic, Willys Corporation, *Elizabeth, N. J.*

SHANNON, GEORGE A., chief draftsman, Paige-Detroit Motor Car Co., *Detroit.*

SHIPLEY, WILLARD J., instructor, Michigan State Auto School, *Detroit.*

SHRUM, A. T., chief draftsman, Walker Vehicle Co., *Chicago.*

SLIGO IRON STORE CO., St. Louis, Mo.

SMITH, HARRY G., assistant engineer, Holley Carburetor Co., *Detroit.*

SMITH, LAWRENCE V., student, Cornell University, *Ithaca, N. Y.*

SMITH, OSCAR A., superintendent, National Acme Co., *Cleveland.*

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THE JOURNAL OF THE SOCIETY OF AUTOMOTIVE ENGINEERS

INDEX TO VOLUME VIII, JANUARY-JUNE, 1921

	PAGES
January	1-74
February	75-204
March	205-292
April	293-388
May	389-516
June	517-620

A

Acceleration

And other tests of engines 4
Tests of steam truck 159

Accidents

Motor vehicle 486
Number of fatal 256
Activities of Sections, S A E 71, 230, 380, 510, 605
Addresses at annual dinner 249

Addresses

Alden, H W 503
Beecroft, David 80, 249
Cowie, R E M 249
Crane, H M 502
Davidson, Prof J B 588
Farm Power dinner 280, 588
Kettering, C F 250
Moskovics, F E 504
Of members desired 148
Roberts, George E 251
Stackhouse, W H 590
Taber, L J 589
Utz, J G 504
Vincent, J G, presidential 95
Vincent, J G 505
Adjustable-pitch propellers 473

Administrative Committees, S A E

Personnel 200
Work of 95
Aerial transportation as a business proposition (G L Martin) 347
Aerial transportation of the immediate future (R H Upson) 423, 593
Aerodynamics propeller theories and 468
Aeronautic handbook 96
Aeronautic propeller design (F W Caldwell) 419, 467

Aeronautic Division, S A E

Personnel 200, 290, 294
Report at annual meeting 169
Result of letter ballot 382

Aeronautic Session

Program for annual meeting announced 1
Review of, at annual meeting 76

Aeronautics

Adjustable-pitch and reversible propellers 473
American pilots 221
America's first airway 330
Micarta and steel propellers 471
Micarta propellers 471
National Advisory Committee's 5-ft. wind tunnel 489
Photographic recording of small motions 50
Propeller design 419, 467
Propeller stresses 476
Propeller testing 477
Propeller theories and aerodynamics 468
Reversible propellers 473
Steel propellers 471
Transportation of the immediate future 423

Agricultural Implements

Motor cultivator 505
Plowing speeds 277
Agriculture in China 403

Agriculture

Basic industry 506
County agent 506
Education and 506
Effect of war 506
In China 403
Tractor on corn-belt farms 511
Use of machinery 506
Air and exhaust supercompression 528
Aircraft laws 199

Aircraft

Development 100
Impediments to commercial transport 565
Laws 199
Suggested business uses for 563
Air Mail operation and maintenance cost 122

Air Mail Service

Operation and maintenance cost 122
Progress 291
Should be extended 569
United States survey flight 134
Airplane stress analysis 53

Airplanes

Armored 24
Compression ratio and thermal efficiency of engines 266, 424
Developed during the war 18
Development of engines 336
Engines 20
Excellent condition of, on Alaskan expedition 229
Helicopter versus 126
Landing fields 567
Landing in thick weather 568
New wing designs 274
Pulitzer trophy race 13
Safe and reliable service 565
Some experiments on thick wings with flaps 271, 380, 421
Statical longitudinal stability of 128
Stress analysis 53
Tested in wind tunnel 495
Tests of four master wing sections 271
Weather and navigation aids 567
Air standard efficiencies for engines 525
Air-temperature regulation effects on fuel economy (R E Fielder) 119, 499
Air transportation and the business man (V E Clark) 563
Alaskan flying expedition (First-Lieut St Clair Streett) 222

Alcohol

Carburetion of 279, 328
Conditions necessary for proper use of 330
Developing a tractor engine 328
ALDEN, H W, ON AUTOMOTIVE OBLIGATIONS TOWARD HIGHWAY DEVELOPMENT 161, 425
ALDEN, H W, ON ENGINEER'S PLACE IN AUTOMOTIVE INDUSTRY 503

Alloys

Brinell tests of bearing 152
Elevated-temperature compression tests of bearing 151
High-temperature properties of white-metal bearing 149
Lead in white-metal bearing 154
Long-period heating of bearing 154
Preparation of 149
Aluminum for various parts of automobile 396
Aluminum pistons (Frank Jardine and Ferdinand Jehle) 397

Aluminum

Constant-clearance pistons 104
Pistons 397
Use for automobile parts 396
American aeronautic pilots 221
American Engineering Standards Committee, representatives 12
American merchant marine 16
American technical schools 592
America's first airway 330

Annual Meeting, S A E

Discussion of papers 419
Program announced 1
Reviewed 75
Anti-freezing solutions 277
Application of carriage experience to automobile construction 286
Application of steam power to an automotive truck (L L Scott) 155, 601
Armament development, problems of 336
Army, educational system of 513
Artillery automotive materiel, recent development of (Capt J B Haney) 375
Atomization of fuel at low temperatures, mechanical 26
Autoignition 215
Automobile body construction (P E Stone) 404
Automobile exhaust gases and vehicular-tunnel ventilation (A C Fieldner, A A Straub and G W Jones) 295, 450
Automobiles aid all occupations 539

Automobiles

Aid all occupations 539
Aluminum for various parts 396
Aluminum pistons in engines 397
Application of carriage experience 286
Body construction 404
Body engineer and his relation to the industry 365, 436
Body lines 124
Can body weight be reduced? (C A Heergeist) 285, 432
Characteristics with ignition on 327
Chassis deflection 405

Chassis design for fuel economy 167
Conflict between art and economy 366
Consequential advantages of weight reduction 396
Cooperation of the oil and industries 43
Design of transmission and axle gears 390
Development possibilities in construction 405
Dragging brakes 167
Elements of fuel economy 543
Exhaust gases and vehicular-tunnel ventilation 295, 450
Heavy greases 167
Instantaneous current and voltage values in a battery 319
Limitations in weight reduction 286
Metal bodies and construction features 404
Minor and general considerations 124
Need for attention to details of body 367
Need for greater service accessibility in design 257, 598
Need for researches on parts 255, 439
Number of fatal accidents 256
Passenger body-designing problems 306, 432
Possibilities for improvement in current models 264
Possible improvements suggested by survey 259
Prevailing body types 123
Relative motion of parts 167
Safety lessons for drivers 12
Schools of body draftsmanship 437
Seasoning of wood for body 404
Status of design for service accessibility 257
Style in bodies 123, 434
Suggested rating rule for racing 118, 440
Underlying principles of electrical ignition 570
Utilization of present fuel 26
Automotive obligations toward highway development (H W Alden) 161, 425
Automotive progress, milestone of 56
Automotive radiators (K F Walker) 127

Automotive Vehicles

Application of steam power to 601
Cooperation of, and oil industries 42
Industrial problems 98
Milestone of progress 56
Obligations toward highway development 161, 425
Possible fuel savings in engines 3
Recent development of artillery materiel 375
Utilization of present fuel 26
Average composition of exhaust gases and completeness of combustion 302

Aviation

Aerial transportation as a business proposition 347
Air mail operation and maintenance costs 122
Air mail survey flight 134
Airplane versus helicopter 126
Alaskan expedition 222
Alaskan expedition flying over Canada 224
Alaskan expedition flying over mountains and glaciers 228
Bad weather encountered on Alaskan expedition 227
Civilian 45
Commercial, in the eastern hemisphere 422
Design requirements of commercial 135, 419
Desirable future developments 143
Development of commercial transportation 349
Engine lubricating oil 220
Equipment development 338
Federal regulations 348
Financial aspects of 568
Forest Patrol 338
Fostering of commercial 250
Fundamental factors of transportation 593
Government aid 569
Hecter fuel and gasoline compared 168
Influence of war on commercial 140
Inherent value of speed 595
Insurance 348
International civil organization 418
Liberty and motorcycle oil 220
Long-distance flight 208
Misdirected development 136
Pigeons in Naval 291
Problems of armament development 336
Questionable future developments 142
Radio telephone 58
Recent advances 18
Recent progress in military 335
Relation of military and commercial 25
Reliability of air transportation 347
Start of Alaskan expedition 222
Terminals 348
Time-value cargo classification 596
Transportation and the business man 563
Transportation of the immediate future 593
Two classes of service 347

Axle and Wheel Division, S A E

Personnel 606
Proposed 294
Axle design, rear 357

B

Bailey, B F, on Underlying Principles of Electrical Ignition 570
Balance used in wind tunnel 491
Ball bearing standardization, international (R S Burnett) 577

Ball and Roller Bearings Division, S A E

Personnel 200, 290, 603
Report at annual meeting 172
Result of letter ballot 382
Bane, Col T H, on Recent Advances in Aviation 18
Basic industry 506

Battery Division, S A E, personnel 200
Battery and magneto-ignition similarities 572

Battery

Characteristics with ignition on 327
Effects of compression on 323
Effect of temperature of engine on 322
Instantaneous current and voltage values in a 319
Variation in voltage and current in 320
Beecroft, David, address 80, 249

Bodies

Can automobile weight be reduced? 432
Lines of 124
Passenger-automobile designing problems 432
Prevailing types 123
School of draftsmanship 437
Style in automobile 123, 434
Body engineer and his relation to the automotive industry (Kingston Forbes) 366, 436

Body Engineering Session

Program for annual meeting announced 1
Review of, at annual meeting 80
Brakes, dragging 167
Bramley-Moore, S, on Developments in Transmission 350
Breed, H E, on Variable Factors in Highway Design 238, 425
Buckingham, Earle, on Inspection and Testing in Interchangeable Manufacture 57
Bureau of Standards fuel study, resume of (H C Dickinson) 450, 482
Burnett, R S, on International Ball Bearing Standardization 577

C

Caldwell, F W, on Aeronautic Propeller Design 419, 467
Can automobile body weight be reduced? (C A Heergeist) 285, 432

Canal Barges

Engine requirements 60
Power required 61
Canby, A T, on Nature of Flame Movement in a Closed Cylinder 209, 449
Carbon in shale 63
Carbureters, metering characteristics of six stock 555
Carburetion of alcohol (A W Scarratt) 279, 328
Care and maintenance of motor trucks (N J Smith) 331, 602
Carnival and dinner, S A E 2
Cars, tank 50

Chain Division, S A E

Activities 512
Personnel 200, 290
Characteristics with the ignition on 327
Chassis deflection 405
Chassis design for fuel economy (A L Putnam) 167, 441
Chassis, springing of 256

Chassis Design Session

Program for annual meeting announced 1
Review of, at annual meeting 81
Chemical phases of fuel problem 44
Chemical theory of Langmuir 318
Chevrolet, Louis, on High-Speed Engines of Small Piston Displacement 368
Chicago meeting and dinner, S A E 205
Chicago truck and tractor meeting, discussion of papers 598
China, agriculture in 403
Civilian aviation 45
Clark, V E, on Air Transportation and the Business Man 563
Clarkson, C F, on Cleveland Tire Meeting 14
Clearance for pistons 402
Clerk, Sir Dugald, on Cylinder Actions in Gas and Gasoline Engines 523
Cleveland Tire Meeting (C F Clarkson) 14
Clutch, cone 350
Coal, low-temperature distillation of 42
Columbus Tractor Show, Exhibit of S A E 281
Combustion, heat of 550
Commerce and war 94
Commercial aviation in the eastern hemisphere (E P Warner) 422

Commercial Aviation Session

Program for annual meeting announced 1
Review of, at annual meeting 82
Commercial motorboats and the Diesel engine (G C Davison) 46
Commercial reaction 118

Committees

Meetings report at annual meeting 79
Standards, S A E, report at annual meeting 79, 169
Community, farm and 17

Comparison of ordinary wood with plywood 480
Compression and lubrication on current and voltage in battery, effect of 323
Compression and the fuel problem 45
Compression ratio and thermal efficiency of airplane engines (S W Sparrow) 266, 424

Compression

Effect of, on current and voltage in a battery 323
Exhaust 528
Fuel problem and 45
Higher piston ratios 103
Ratio and thermal efficiency of airplane engines (S W Sparrow) 266, 424

Conditions necessary for proper use of alcohol 330
Cone clutch 350
Conference on traffic regulation 305
Consequential advantages of weight reduction (L H Pomeroy) 396
Cooperation of the automotive and oil industries (C F Kettering) 43
Correct addresses of members 148
Correcting road failures 164

Costs

Air mail operation and maintenance 122
First, of engines 46

Council report at annual meeting 78

Council Meetings

December, 1920 11
January, 1921 200
February, 1921 208
March, 1921 294
April, 1921 509, 603

Cowie, R E M, address 249
Cracking processes 52
CRANE, H M, ON ENGINEERING AS A PROFESSION AND THE VALUE OF AN ENGINEERING EDUCATION 496
CRANE, H M, ON ENGINEER'S PLACE IN AUTOMOTIVE INDUSTRY 502
CRANE, H M, ON SUGGESTED RATING RULE FOR RACING CARS 118, 440
Crankcase conditions 231
Crankcase oil, dilution of (W F Parish) 231
Crude oil 56
Crude oil production in 1920 409
Crude rubber imports 270
CULLEN, T F, ON NEED FOR GREATER SERVICE ACCESSIBILITY IN CAR DESIGN 257, 598
Cup grease specification 221
Currency, world debt and paper 229
Current and voltage values in a battery, instantaneous (G W Vinal and C L Snyder) 319
Current standardization work 381, 512, 606
Cylinder actions in gas and gasoline engines (Sir Dugald Clerk) 523

Cylinders

Actions in gas and gasoline engines 523
Characteristic turbulence in typical 584
Effect of turbulence on flame propagation 579
Flame movement at normal temperature and pressure 210
Flame propagation and recompression 532
Flame the actual working fluid 525
Gaseous explosions 531
Intake flow in manifolds and 282
Knocking, pinking and detonating 526
Nature of flame movement in closed 209, 449
Residual turbulence 529
Short statement of actions 523
Two methods of producing turbulence 582
Cylindrical parts, fits for 230

D

Dangers of prosperity 253
Data on Illinois tractors 487
Data sheets, S A E, March, 1921 542
Davidson, Prof J B, address 588
DAVISON, G C, ON COMMERCIAL MOTORBOATS AND THE DIESEL ENGINE 46
Debt, world, and paper currency 229
December Council Meeting 11
December refinery statistics 367
DEED, WILLIAM J, ON MOTORBOAT STANDARDIZATION FROM THE NAVAL-ARCHITECT'S VIEWPOINT 116
Depreciation 385
Description of thermostat 120
Design of piston 398
Design of transmission and axle gears 390
Design requirements of commercial aviation (Grover C Loening) 135, 419
Desired manifold temperature 121

Detonation

Engine 241
Further experiments 484
What is 483

Detroit house numbers changed 16
Developing an alcohol tractor engine 328
Development of airplane engines 336
Development of commercial aerial transportation 349
Development of industry 496
Developments in transmission (Capt S Bramley-Moore) 350
DICKINSON, H C, ON POSSIBLE FUEL SAVINGS IN AUTOMOTIVE ENGINES 3
DICKINSON, H C, ON RESUME OF BUREAU OF STANDARDS FUEL STUDY 450, 482
Dilution of crankcase oil (W F Parish) 231

Dinners

Addresses at annual 249
Chicago, S A E 205
Farm Power addresses 280, 588
Farm Power, S A E 277

Discrepancy between part and drawing in manufacture 57
Discussion of papers at the Chicago truck and tractor meeting 598
Distillation of shale 63
Drainage investigations 344
Drainage problem of roads 341
Duties of a piston 397

E

Economical size of farm 256
Economy and performance demands (J G Vincent) 440, 507

Economy

Air-temperature regulation effects on fuel 119, 449
Chassis design for fuel 167, 441
Conflict between art and 366
Elements of automobile fuel 543
Fuel 482
Fuel and lubricant, in motorboats 47
Ideal engine 115
Lubricant, in motorboats 47
Performance demands and 440, 507
Size of farm 256

Education

American technical school 592
Effect on agriculture 506
Value of an engineering 496

Educational system of the Army 513
Effect of compression and lubrication on current and voltage in battery 323
Effect of heat on maximum horsepower 8
Effect of long-period heating 154
Effect of small percentages of lead 154
Effect of temperature of engine 322
Effect of tire sizes 168
Effect of turbulence on flame progagation 579
Effect of war on agriculture 506

Efficiency

Air standard for engines 525
Compression ratio and thermal, of airplane engines 266, 424
Influence of air and fuel proportions on engine 553
Mechanical, of engines with particular reference to part-load conditions 556
Power transmission 552
Volumetric of engine 122

Einstein's theory appears well founded 318
Electric drive and the steam engine 49

Electrical Equipment Division, S A E

Activities 513, 606
Personnel 290
Report at annual meeting 175, 190
Result of letter ballot 382

Electric Transportation Division, S A E

Personnel 12
Report at annual meeting 174
Result of letter ballot 382

Electric Vehicle Division, S A E, personnel 200, 290
Electromagnetic theory 318
Elements of automobile fuel economy (W S James) 543
Employment, analysis of industrial 390
End point, high, of fuels 43

Engine Division, S A E

Activities 512, 606
Personnel 290, 603
Report at annual meeting 178
Result of letter ballot 382

Engineer and his relation to the automotive industry, body (Kingston Forbes) 365, 436
Engineer should cooperate 505
Engineering analysis applied to truck selling (N J Ocksreider) 600
Engineering as a profession and the value of an engineering education (H M Crane) 496
Engineering, leadership in conservation movement 508
Engineering museum 69
Engineering, two forms of 504
Engineering viewpoint, fuel problem in relation to (A L Nelson) 101, 450
Engineer's place depends on himself 503
Engineer's place in automotive industry 502
Engineer's place in industry 496

Engines

Acceleration and other tests 4
Air and exhaust supercompression 528
Airplane 20
Air standard efficiencies 525
Aluminum pistons 397
Apparatus for testing 110
Application on the farm 13
Aviation lubricating oil 220
Basic principles of the 107
Canal-barge requirements 60
Carburetion of alcohol 279
Causes and types of vibration 55
Characteristic turbulence in typical cylinders 584
Charge quantity control 549
Commercial motorboats and Diesel 46
Comparative tests 112
Compression and the fuel problem 45
Compression ratio and thermal efficiency of airplane 266, 424

Conditions necessary for proper use of alcohol 330
Cone clutch 350
Constant-clearance pistons 104
Control 157
Critical speeds 54
Cylinder actions in gas and gasoline 523
Design 507
Desirable fuel and its preparation 3
Detonation 241
Developing an alcohol tractor 328
Development of airplane 336
Developments in transmission 350
Economy and performance demands 440, 507
Effect of heat on maximum horsepower 8
Effect of temperature on voltage and current 322
Effect of turbulence on flame propagation 579
Electric drive and the steam 49
First cost 46
Flame propagation and recompression 532
Flame the actual working fluid 525
Friction and power 232
Fuel and lubricant economy 47
Fuel consumption in automotive 158
Fuel oil for Diesel 220
Gas pressure transformation loss 552
Gaseous explosions 531
General details of construction of German submarine 411
German submarine Diesel 410
High-speed, described 369
High-speed, of small piston displacement 368
Ideal economy 115
Ignition from the engineman's viewpoint 307
Influence of air and fuel proportions upon efficiency and power 553
Knocking, pinking, detonating 526
Largest internal-combustion, vessel 488
Maneuvering gear on German submarine 413
Mechanical efficiency of, with particular reference to part-load conditions 556
Mechanical reversing gears 48
Methods for measuring turbulence 585
Nature of flame movement in a closed cylinder 209, 449
New principle of suspension 54, 440
Oil consumption in automotive 158
Packard fuelizer 240
Possible fuel savings in automotive 3
Power required to drive the car at constant speed 102
Reclamation of used oil 233
Relative merits of large slow-speed and small high-speed 561
Reliability of German submarine 414
Residual turbulence 529
Reversibility 60
Rich mixture for starting 495
Specific heat of flame 533
Specification for aircraft and motorcycle oil 220
Specifications for high-speed 368
Steam, and the electric drive 49
Tests 328
Tests at Ohio State University 255
Two methods of producing turbulence 582
Uniform distribution with fuel 240
Universal-joint and gearbox design 352
Volatility of internal-combustion, gasoline 145, 449
Volumetric efficiency 122
Water consumption in automotive 158
Epicyclic gears 355
Era of specialization 502
Evaporation of crude oil 416
Exhaust supercompression 528
Exhibit at Columbus Tractor Show, S A E 281
Exports of mineral oil 317

F

Farm and community 17
Farm Power dinner addresses 588
Farm Power meeting and dinner, S A E 277
Farms, economical, size of 256
Federal flying regulations 348
Federal Highway commission urged 338
FIELDER, R E, ON AIR-TEMPERATURE REGULATION EFFECTS ON FUEL ECONOMY 119, 449
FIELDNER, A C, ON AUTOMOBILE EXHAUST GASES AND VEHICULAR-TUNNEL VENTILATION 295, 450
Final inspection of work 58
Finance Committee, S A E, personnel 200
Financial aspects of aviation 568
Fits for cylindrical parts 230
Flame movement at normal temperature and pressure 210
Flame the actual working fluid 525

Flame Movement

At normal temperature and pressure 210
Influence of temperature and pressure 213
Influence of turbulence 212

Flame Propagation

Effect of turbulence 579
Recompression 532

FORBES, KINGSTON, ON BODY ENGINEER AND HIS RELATION TO THE AUTOMOTIVE INDUSTRY 365, 436
Forms of engineering 504

Frames Division, S A E

Activities 381
Personnel 290, 294
FREEMAN, J R, JR, ON HIGH-TEMPERATURE PROPERTIES OF WHITE-METAL BEARING ALLOYS 149
French and Spanish coasts, landfalls on 315
Friction and power in engines 232
Friction in organization 10
FROESCH, CHARLES, ON PRESENT STATUS OF THE ISOLATED GAS-ELECTRIC GENERATING PLANT 28
Fuel and lubricant economy 47
Fuel consumption in tractors 393
Fuel knock 558
Fuel oil for Diesel engines 220
Fuel problem in relation to engineering viewpoint (A L Nelson) 101, 450
Fuel research 200
Fuel research developments (C F Kettering) 448

Fuel Session

Program for annual meeting announced 2
Review of, at annual meeting 84

Fuelizer

Hot-spots versus 242
Ignition for 242
Packard 240

Fuels

Air-temperature regulation effects on economy 119, 449
Autoignition 215
Carburetion of alcohol 279, 328
Characteristics and economy 482
Charge quantity control 549
Chassis design for economy 167, 441
Chemical phases 44
Compression and 45
Conditions for proper use of alcohol 330
Consumption in automotive engine 158
Consumption in tractors 393
Desirable, and its preparation for automotive engines 3
Elements of automobile, economy 543
Heat of combustion 550
Hecter and aviation gasoline compared 168
High end-points 43
Impossibility of atomization 26
Influence of air and, proportions upon engine efficiency and power 553
Jacket-water temperature and intake-manifold pressure 8
Lighting plant problem 41
Low-temperature distillation of coal 42
Lubricant economy and 47
Mechanical atomization at low temperatures 26
Mixing and vaporization 548
Nature of knock 217
Notes on current research 131
Oil for Diesel engines 220
Possible savings in automotive engines 3
Problem in relation to engineering viewpoint 101, 450
Problems 99
Research 200
Research developments 448
Resume of Bureau of Standards study 450, 482
Rich mixture for starting engines 495
Third semi-annual gasoline survey 365
Uniform distribution 240
Utilization of present automotive 26
Vaporizer 105
Volumetric efficiency 122

G

Gas-electric generating plant, present status of isolated (Charles Froesch) 28
Gas oil 52
Gas pressure transformation loss 552
Gaseous explosions 531
Gases, automobile exhaust, and vehicular-tunnel ventilation 295, 450
Gasoline consumption by states in 1920 276
Gasoline production in November 269

Gasoline

Consumption by states in 1920 276
Cracking processes 52
Cylinder actions in gas and, engines 523
Economy and performance demands 440, 507
Heat of combustion 550
Hecter and aviation, compared 168
Physical meaning and measurement of volatility 146
Production in November 269
Production statistics 118
Quantity and quality 51
Requirements for full utilization of inherent volatility 147
Specifications 219
Testing 219
Third semi-annual survey 365
Volatility of internal-combustion engine 145, 449
Volumetric proportions of a combustible mixture 145
Gearbox design 352

Gears

Comparison of two types of worm 363
Design of transmission and axle 390
Determination of points of contact 360
Epicyclic 355
Maneuvering, German submarine engine 413
Mechanical reversing 48
Research work needed 539
Straight-line generation 362
Worm, design 358
German Submarine, Diesel engine (Lieut-Com H C Gibson) 410
GIBSON, H C, LIEUT-COM, ON GERMAN SUBMARINE, DIESEL ENGINE 410

SIDE GUIDE & GRIPPER

GOLDBECK, A T, ON INVESTIGATIONS OF ROAD SUBGRADES 339, 426
Government aid 569
Grand Central Terminal 70
Graphite lubricants 374
Gun-mounts 377
GUTHRIE, R G, ON RELATION OF RECOVERANCE TO THE FATIGUE OF METALS 65

H

HALLETT, G E A, ON IGNITION FROM THE ENGINEMAN'S VIEWPOINT 307
HANDBOOK, NEW S A E 346
HANEY, CAPT J B, ON RECENT DEVELOPMENT OF ARTILLERY AUTOMOTIVE MATERIEL 375
HANSCOM, C D, ON SOME EXPERIMENTS ON THICK WINGS WITH FLAPS 271, 380, 421
Heat of combustion 550

Heat

Effect of long-period 154
Effect on maximum horsepower 8
Of combustion 550
Specific, of flame 533
Heavy traffic pavements 480
Hecter and aviation gasoline compared 168
HEERGEIST, C A, ON CAN AUTOMOBILE BODY WEIGHT BE REDUCED? 285, 432
Helicopter 126

Helicopter

Airplane versus 126
Possible line of thought 126
HERSCHEL, DR W H, ON LUBRICATING OIL TESTS 481
High-speed engines of small piston displacement (Louis Chevrolet and C W Van Ranst) 368
High-temperature properties of white-metal bearing alloys (J R Freeman, Jr, and R W Woodward) 149
Highway research 16
Highway Road-Construction (W E Williams) 163, 425
Highway traffic regulations 53
Highway transport 390, 562
Highway session, review of, at annual meeting 86
Highways 542

Highways and Roads

Automotive obligations toward development 161, 425
Bearing value of soils 164
Construction 163, 425
Construction materials 64
Correcting failures 164
Drainage problem 341
Federal Commission urged 338
Foundation, drainage, surfacing and maintenance 238
Good 542
Heavy traffic pavements 480
Impact 166
Investigations of subgrades 339, 426
Laboratory investigations of subgrades 342
Minimum width of 20 ft for trunk 64
Politics in the construction 238
Problems 98
Reinforcement 166
Research 16
Soft subgrades 340
Tests at Camp Humphreys 340
Traffic regulations 53
Transport 390, 562
Trunk 64
Type of pavement 238
Ultimate 166
Variable factors in design 238, 425
HILL, H H, ON PETROLEUM REFINING PROCESSES AND PROBLEMS 51
HORNING, H L, ON TURBULENCE 579

Horses

Comparative cost of tractors and 488
Replacement of 487
Hot-spots versus fuelizer 242
House Committee, S A E, personnel 200
House numbers changed, Detroit 16
HOWARD, F A, ON VOLATILITY OF INTERNAL-COMBUSTION ENGINE GASOLINE 145, 449
Hysteresis loop, mechanical 417

I

Ignition from the engineman's viewpoint (Capt G E A Hallett) 307
Ignition timing 557

Ignition

Battery and magneto similarities 572
Characteristics with, on 327
Engineman's viewpoint of 307
Fuelizer 242
Short and long sparks 574
Spark lag 575
Timing 557
Underlying principles of electrical 570
Illinois tractors, data on 487
Impact 166
Impact tests on trucks (E B Smith) 17
Imports, crude rubber 270
Improvements in motor-vehicle design 331
Industrial depreciation 385
Industrial depression 251
Industrial employment analysis 390
Industrial problems 98
Industrial rehabilitation 252
Industry, research the bond between the university and (A E White) 497
Influence of air and fuel proportions upon engine efficiency and power 553
Influence of temperature and pressure on flame propagation 213
Influence of turbulence on flame movement 212
Inspection and testing in interchangeable manufacture (Earle Buckingham) 57

Inspection

Final, of work 58
Shop, methods and personnel 57
Instantaneous current and voltage values in a battery (G W Vinal and C L Snyder) 319
Intake flow in manifolds and cylinders (P S Tice) 282
International ball bearing standardization (R S Burnett) 577
International civil aviation organization 418
Investigations of road subgrades (A T Goldbeck) 339, 426
Iron and Steel Division, S A E, personnel 200, 290, 603

Isolated Electric Lighting Plant Division, S A E

Activities 381, 512
Personnel 290, 603
Isolated gas-electric generating plant, present status of the (Charles Froesch) 28

J

Jacket-water temperature and intake-manifold pressure 8
JAMES, W S, ON ELEMENTS OF AUTOMOBILE FUEL ECONOMY 543
JARDINE, FRANK, ON ALUMINUM PISTONS 397
JEHLE, FERDINAND, ON ALUMINUM PISTONS 397
JOHNSON, A F, ON PASSENGER-AUTOMOBILE BODY-DESIGNING PROBLEMS 306, 432
JONES, G W, ON AUTOMOBILE EXHAUST GASES AND VEHICULAR-TUNNEL VENTILATION 295, 450

K

Kerosene

Prime white 219
Quantities 52
Kettering, C F, address 250
KETTERING, C F, ON COOPERATION OF THE AUTOMOTIVE AND OIL INDUSTRIES 43
KETTERING, C F, ON FUEL RESEARCH DEVELOPMENTS 448
Knock, fuel 558
Knocking, pinking, detonating in engines 526

L

Laboratory investigations of subgrades 342
LACY, V E, ON SOME INLAND WATERWAY TRANSPORTATION PROBLEMS 59
Landfalls on the French and Spanish coasts 315
Landing fields 567
Landing in thick weather 568
Langmuir's postulates occupy scientists 318
Largest internal-combustion engine vessel 488
Lead, effect of small percentages of 154
LEWIS, H A, ON NATURE OF FLAME MOVEMENT IN A CLOSED CYLINDER 209, 449
Liberty aero and motorcycle oil 220

Lighting Division, S A E

Activities 512
Personnel 290, 603

Lighting Plants

Characteristics of the ideal farm 33
Common types of 29
Controlling devices 39
Design factors 35
Fuels 41
Service 41
Storage batteries 37
Thirty-two and 110-volt systems compared 40
Voltage regulation 38
LOENING, G C, ON DESIGN REQUIREMENTS OF COMMERCIAL AVIATION 135, 419
Long-distance flight 208
Looping the North Atlantic in the Typhoon (W W Nutting) 314
Low-temperature distillation of coal 42
Lubricants Division, S A E, personnel 290

Lubricants

Aviation engine 220
Fuel and, economy 47
Graphite 369
Heavy greases 167
Liberty aero and motorcycle 220
Oil tests 481
Oils 52, 220
Transmission and cup grease 221
Lubricating oil tests (Dr W H Herschel) 481
Lubricating oils 220

Lubrication

Effect of compression and on current and voltage in battery 323
Oil for low speeds and heavy loads 415

SIDE GUIDE & GRIPPER

M

Machine tool, what is a 346
Machine tools, modern 202
Machinery in agriculture 506
MAGRUDER, W T, ON NEED FOR RESEARCHES ON AUTOMOBILE PARTS 255, 439

Maintenance

Motor-vehicle problems 333
Tractor 376

Manifold

Desired temperature 121
Intake flow in, and cylinders 282
Jacket-water temperature and intake, pressure 8
Manometer in wind tunnel 493
March 1921 issue of data sheets 542
MARTIN, G L, ON AERIAL TRANSPORTATION AS A BUSINESS PROPOSITION 347
MARTIN, MAJOR H S, ON RECENT PROGRESS IN MILITARY AVIATION 335
Mechanical efficiency of engines with particular reference to part-load conditions 556

Meetings

Annual S A E 1
Annual S A E reviewed 75
Chicago S A E 10, 205
Cleveland Tire 14
Columbus S A E 10
Farm Power, S A E 277
Motorboat, S A E 2
Proposed Fall Section 605
S A E Council, December, 1920 11
January, 1921 200
February, 1921 208
March, 1921 294
April, 1921 509, 603
Summer, S A E 265, 293
Summer reviewed 517

Meetings Committee, S A E

Personnel 200
Report 294
Members, addresses of, desired 148

Membership

Council action on 208, 294
Increase of 95
Report at annual meeting 77
Report at December council meeting 12
Report at April council meeting 603
MERCER, G J, ON STYLE IN AUTOMOBILE BODIES 123, 434
Merchant marine, American 16
Metal bodies and construction features 404
Metal fatigue under repeated stresses 417

Metals

Another theory of recoverance 67
Fatigue 66
Fatigue under repeated stresses 417
Mechanical hysteresis loop 417
Relation of recoverance to fatigue 65
Tests for fatigue of metals 418
Metering characteristics of six stock carbureters 555
Methods and apparatus used in obtaining current and voltage values in a battery 319
Methods of computing results of tests on automobile exhaust gases 296
Micarta and steel propellers 471
Milestone of automotive progress 56
Military aviation, recent progress in 335
Minimum width for trunk highways 64
Mining of shale 63

Miscellaneous Division, S A E

Report at annual meeting 179
Result of letter ballot 382
Mixing and vaporization 548
Mixtures, volumetric proportions of combustible 145
MOCK, F C, ON UTILIZATION OF PRESENT AUTOMOTIVE FUEL 26
Modern machine tools 202
Money and credit 252
MOSKOVICS, F E, ON ENGINEERS PLACE IN AUTOMOTIVE INDUSTRY 504
Motions, photographic recording of small 50
Motorboat Division, S A E, personnel 290
Motorboat meeting, S A E 2
Motorboat standardization from the naval-architect's viewpoint (William J Deed) 116

Motorboats

Commercial, and the Diesel engine 46
Standardization from the naval-architect's viewpoint 116
Motor cultivator 505

Motorcycle Division, S A E

Personnel 200, 291
Report at annual meeting 181
Result of letter ballot 382
Motorcycles, Liberty aero and oil 220
Motor vehicles per capita 330
Motor-vehicle safety increasing 486

Motor Vehicles

Acceleration test of steam truck 159
Air-temperature regulation effects on fuel economy 449
Application of steam power to truck 155, 601
Average composition of exhaust gas and completeness of combustion 302
Care and maintenance of 331, 602
Engineering analysis applied to selling 600
Exhaust gases and vehicular-tunnel ventilation 295
Future development 162
Handling repairs 334
Highway transport 390, 562
Maintenance practice 333
Needed improvements in design 331
Per capita 330
Percentage of carbon dioxide in exhaust gas and completeness of combustion 304
Remedies for accidents 486
Road construction and 390
Safety increasing 486
Service requirements 507
Simplification of product 249
Springing of chassis 256
Tests on exhaust gases 295
Tires 507

Museum

Engineering 69
Ordnance 126

N

National Advisory Committee's 5-ft wind tunnel (F H Norton) 489
National Screw Thread Commission report on standards 511
Nature of flame movement in a closed cylinder (C A Woodbury, H A Lewis and A T Canby) 209, 449
Nature of fuel knock 217

Navigation

Looping the North Atlantic in the Typhoon 314
Outbound voyage in Typhoon 314
Typhoon receives two knockdowns 316
Navy pigeons in aviation 291
Nebraska tractor tests 278, 391
Need for greater service accessibility in car design (T F Cullen) 257, 598
Need for researches on automobile parts (W T Magruder) 255, 439
NELSON, A L, ON FUEL PROBLEM IN RELATION TO ENGINEERING VIEWPOINT 101, 450
New principle of engine suspension (S E Slocum) 54, 440
New S A E Handbook 346

Non-Ferrous Metals Division, S A E

Activities 381, 607
Personnel 200, 291, 294, 603
Report at annual meeting 181
Result of letter ballot 382
NORTON, F H, ON NATIONAL ADVISORY COMMITTEE'S 5-FT WIND TUNNEL 489
Notes on current fuel research 131
Number of fatal automobile accidents 256
NUTTING, W W, ON LOOPING THE NORTH ATLANTIC IN THE TYPHOON 314

O

OCKSREIDER, N J, ON ENGINEERING ANALYSIS APPLIED TO TRUCK SELLING 600
Officers, S A E, for 1921 79, 88
Oil-burning vessels 291
Oil pipe lines 27
Oil pools 10
Oils for powerplants 415

Oils

Aviation engine lubricating 220
Consumption in automotive engine 158
Cooperation of the automotive and oil industries 43
Crude 56
Crude production in 1920 409
December refinery statistics 367
Dilution of crankcase 231
Evaporation of crude 416
Exports of mineral 317
Fuel for Diesel engines 220
Gas 52
Liberty aero and motorcycle 220
Lubricating 52, 220
Lubricating, for low speeds and heavy loads 415
Lubricating tests 481
Pipe lines 27
Pools 10
Powerplants 415
Reclamation method 235
Reclamation of used engine 233
Shale 70
Tank cars 50
Operation temperatures of pistons 400
Ordnance museum 126
Outbound voyage of Typhoon 314

P

Packard fuelizer (L M Woolson) 240
Paper currency, world debt and 229
PARISH, W F, ON DILUTION OF CRANKCASE OIL 231

Parts and Fittings Division, S A E

Activities 512, 607
Personnel 200, 291, 603
Subjects assigned 604
Passenger-automobile body-designing problems (A F Johnson) 306, 432

Passenger Car Body Division, S A E

Activities 381, 513
Personnel 291, 294
Subjects assigned 604

Pavement, heavy traffic 480
Percentage of carbon dioxide in exhaust gas and completeness of combustion 304
Petroleum from shale 63
Petroleum refining processes and problems (H H Hill) 51

Petroleum

Refining processes and problems 51
Shale as a source of 63
Standardization of specifications 219
World's production in 1920 349

Photographic recording of small motions 50
Physical meaning and measurement of volatility 146
Pigeons in naval aviation 291
Pilots, American aeronautic 221

Pistons

Aluminum 397
Clearance required 402
Constant-clearance aluminum 104
Designs of 398
Duties of a 397
High-speed engines of small displacement 368
Higher compression ratios 103
Operation temperatures of 400

Plowing speeds 277
Plows 62

Plywood

Comparison of ordinary wood with 480
Varying the number of plies in 486

POMEROY, L H, ON CONSEQUENTIAL ADVANTAGES OF WEIGHT REDUCTION 396
Possible fuel savings in automotive engines (H C Dickinson and S W Sparrow) 3
Possibilities for improvement in current automobile models 264
Possible improvements in automobile design suggested by survey 259
Power on the farm 13
Power transmission efficiency 552

Power

Application of steam power to an automotive truck 155, 601
Influence of air and fuel proportions upon engine 553
Required for canal barges 61
Water 17, 118
Water development 416

Powerplant for wind tunnel 490
Powerplants, oils for 415
Present industrial situation and outlook 253
Present status of the isolated gas-electric generating plant (Charles Froesch) 28
Pressure, influence on flame propagation 213
Prices of S A E publications 208

Production

Crude oil in 1920 409
December refinery statistics 367
Gasoline in November 269
Gasoline statistics 118
World's 1920 petroleum 349

Products, salability of 502

Propellers

Adjustable-pitch and reversible 473
Aeronautic design 419, 467
Micarta and steel 471
Reversible 473
Stresses 476
Testing 477
Theories and aerodynamics 468

Prosperity, dangers of 253
Publication Committee, S A E, personnel 200
Publications of interest 384, 509
Publications, S A E, prices 208
Pulitzer trophy race 13
PUTNAM, A L, ON CHASSIS DESIGN FOR FUEL ECONOMY 167, 441

R

Radiator Division, S A E

Personnel 200, 291, 603
Report at annual meeting 187
Result of letter ballot 382

Radio control of ships 587
Radio telephone 58

Railroads

Electrification 122
Tank cars 50
Valuation 69

Recent advances in aviation (Col T H Bane) 18
Recent development of artillery automotive material (Capt J B Haney) 375
Recent progress in military aviation (Major H S Martin) 335
Reclamation of used engine oil 233
Recoverance to the fatigue of metals, relation of (R G Guthrie) 65

Recoverance

Relation of, to fatigue of metals 65
Theory of 67

Reinforcement for roads 166
Relation of recoverance to the fatigue of metals (R G Guthrie) 65
Relative motion of automobile parts 167
Reliability of air transportation 347
Repairs to motor vehicles 334

Reports

Council at annual meeting 78
Meetings Committee at annual meeting 79
Membership at annual meeting 77
Membership at April council meeting 603
National Screw Thread Commission 511
Sections Committee at annual meeting 79
Standards Committee at annual meeting 79
Treasurer's at annual meeting 77
Treasurer's at April council meeting 603

Requirements for full utilization of inherent volatility 147
Research department of the Society 270
Research the bond between the university and industry (A E White) 497

Research

Action at Council meeting 208
Bond between the university and industry 497
Electromagnetic theory 318
Fuel 200
Fuel developments 448
Hesitation to encourage 497
Need for, on automobile parts 255, 439
Notes on current fuel 131
Situation in Michigan 498
Work on gears needed 539

Research Committee, S A E personnel 200

Research Department, S A E

Formation 270
Plans discussed 294, 603
Scope of work 603

Research work on gears needed 539
Results of tests of automobile exhaust gases 298
Resumé of Bureau of Standards fuel study (H C Dickinson) 450, 482
Reversible propellers 473
"Rich" mixture for starting engine 495

Roads and Highways

Automotive obligations toward development 161, 425
Bearing value of soils 164
Construction 163, 425
Construction materials 64
Correcting failures 164
Drainage problem 341
Federal Commission urged 338
Foundation, drainage, surfacing and maintenance 238
Good 542
Heavy traffic pavements 480
Highway research 16
Impact 166
Investigations of subgrades 339, 426
Laboratory investigations of subgrades 342
Minimum width of 20 ft for trunk 64
Politics in the construction 238
Problems 98
Reinforcement 166
Soft subgrades 340
Tests at Camp Humphreys 340
Traffic regulations 53
Transport 390, 562
Trunk 64
Type of pavement 238
Ultimate 166
Variable factors in design 238, 425

Roberts, George E, address 251
ROSA, E B, ON SCIENTIFIC WORK OF THE GOVERNMENT 69
Rubber, crude, imports 270

S

S A E

Activities of Sections 71, 95, 201, 230, 380, 510, 605
Aeronautical session at annual meeting 76
Annual meeting 1
Annual meeting reviewed 75
Body engineering session at annual meeting 80
Chassis design session at annual meeting 81
Chicago meeting 10
Chicago meeting and dinner 205
Columbus meeting 10
Commercial aviation session at annual meeting 82
Cooperation with other organizations 96
Council and staff 96
Council meetings:
December, 1920 11
January, 1921 200
February, 1921 208
March, 1921 294
April, 1921 509, 603
Council report at annual meeting 78
Discussion of annual meeting papers 419
Discussion of Chicago truck and tractor meeting papers 598
Exhibit at the Columbus tractor show 281
Farm power meeting and dinner 277
Fuel session at annual meeting 84
Highway session at annual meeting 86
Membership report at annual meeting 77
Motorboat meeting 2
New HANDBOOK 346

Officers for 1921 79, 88
Prices of publications 208
Problems of 97
Research department 270
Research department plans 294
Sections activities 71, 95, 201, 230, 380, 510
Semi-annual meeting 208
Standards committee, 1921 288
Summer meeting at West Baden 265, 293, 389
Summer meeting reviewed 517
Treasurer's report at annual meeting 77
Treasurer's report at December council meeting 11
Treasurer's report at April council meeting 603
Truck and tractor meeting at Chicago 205
Safe and reliable airplane service 565

Safety

Lessons for automobile drivers 12
Motor vehicle increasing 486
Salability of automotive products 503
SCARRATT, A W, ON CARBURETION OF ALCOHOL 328

Schools

American technical 592
Body draftsmanship 437
Scientific work of the Government (E -B Rosa) 69
SCOTT, L L, ON APPLICATION OF STEAM POWER TO AN AUTOMOTIVE TRUCK 155, 601

Screw-Thread Division, S A E

Activities 381
Personnel 291
Subjects assigned 604
Screw threads, standards 511
Seasoning of wood, proper 404
Sectional Committee on Gears of the American Engineering Standards Committee, representative 294

Sections, S A E

Activities 71, 95, 201, 230, 380, 510, 605
Financial support 604
Dayton established 208
Proposed Fall meetings 605
Report at annual meeting 79

Semi-Annual Meeting, S A E

Announced 208
Reviewed 517
Service for lighting plants 41
Shafts, torsional strength of multiple-splined 129, 440
Shale oil 70

Shale

Form of carbon in 63
Mining and distillation 63
Oil 70
Petroleum from 63

Ships

Largest internal-combustion engine 488
Oil-burning 291
Radio control of 587
Shop inspection methods and personnel 57
Short and long sparks 574
SJOGREN, O W, ON NEBRASKA TRACTOR TESTS 391
SLOCUM, S E, ON NEW PRINCIPLE OF ENGINE SUSPENSION 54, 440
SMITH, E B, ON IMPACT TESTS ON TRUCKS 17
SMITH, N J, ON CARE AND MAINTENANCE OF MOTOR TRUCKS 331, 602
SNYDER, C L, ON INSTANTANEOUS CURRENT AND VOLTAGE VALUES IN A BATTERY 319

Soils

Bearing power 164
Bearing value test 343
Drainage investigations 344
Drainage problem 341
Some considerations in tractor service (J C Thorpe) 540, 598
Some experiments on thick wings with flaps (C D Hanscom) 271, 380, 421
Some inland waterway transportation problems (V E Lacy) 59
Spanish coasts, landfalls on French and 315
Spark lag 575

Sparks

Lag 575
Short and long 574
SPARROW, S W, ON COMPRESSION RATIO AND THERMAL EFFICIENCY OF AIRPLANE ENGINES 266, 424
SPARROW, S W, ON POSSIBLE FUEL SAVINGS IN AUTOMOTIVE ENGINES 3
Specialization, era of 502
Specific heat of flame 533

Specifications

Cup grease 221
Gasoline 219
Engine high-speed 368
Kerosene 219
Standardization of petroleum 219
Transmission lubricant 221
Valve-steel 513

Speeds

Critical, of engines 54
Engine critical 54
Inherent value of 595
Plowing 277
SPICER, C W, ON TORSIONAL STRENGTH OF MULTIPLE-SPLINED SHAFTS 129, 440
Springing of chassis 256
Springs Division, S A E, personnel 200, 291
Stackhouse, W H, address 590

Standardization

Ball bearing, international 577
Current work 381, 512, 606
Development of tire 14
Motorboat from the naval-architect's viewpoint 116
Motorboats 116
National Screw Thread Commission reports 511
Petroleum specifications 219
Result of letter ballot on standards 382
Rules governing, S A E 288

Standards Committee, S A E

1921 288
Appointments to membership 288
Data sheets, March, 1921 542
Expenditures 289
Functions 288
Meetings 289
Organization 288
Personnel 200, 288, 290
Procedure of business 289
Publicity 289
Records of meetings 289
Report at annual meeting 79, 169
Report at council meeting 208
Stationery 289
Work in progress 289
Work of 95
Statical longitudinal stability of airplanes 128

Stationary Engine Division, S A E

Activities 381, 513
Personnel 200, 291
Subjects assigned 604
Status of car design for service accessibility 257
Steel propellers 471
Steel, valve specifications 513
STONE, P E, ON AUTOMOBILE BODY CONSTRUCTION 404
Storage batteries for lighting plants 37
Storage Battery Division, S A E, personnel 291
STRAUB, A A, ON AUTOMOBILE EXHAUST GASES AND VEHICULAR TUNNEL-VENTILATION 295, 450
Street traffic in London and New York 10
STREETT, FIRST-LIEUT ST CLAIR, ON ALASKAN FLYING EXPEDITION 222

Stresses

Airplane, analysis of 53
Metal fatigue under repeated 417
Propeller 476
Style in automobile bodies (G J Mercer) 123, 434

Subgrades

Drainage investigations 344
Drainage problem 341
Investigations of road 339, 426
Laboratory investigations 342
Soft 340
Submarine Diesel engine, German (Lieut-Com H C Gibson) 410
Suggested rating rule for racing cars (H M Crane) 118, 440
Summer Meeting, S A E 265

Summer Meeting, S A E

Announced 293
Recreation 293
Reviewed 517
Sports 390
Technical sessions 293, 389
Tentative program 389
Transportation arrangements 294, 389
Superpower survey 122

T

Taber, L J, address 589
Tank cars 50
Tanks, army 379
Technical schools, American 592
Technical sessions at summer meeting 293, 389
Telephone, radio 58

Temperatures

Desired manifold 121
Effect of engine on voltage and current 322
High, properties of white-metal bearing alloys 149
Influence on flame propagation 213
Piston 400
Variation in street 121

Tests

Acceleration of engines and other 4
Acceleration of steam truck 159
Airplanes in wind tunnel 495
Apparatus for engine 110
Apparatus used for metal 150
Bearing value of soil 343
Bureau of Standards fuel study, resumé of 450, 482
Comparative engine 112
Comparative, with and without thermostat 120

Current and voltage values in a battery 319
Elevated temperature Brinell 152
Elevated-temperature compression of alloys 151
Engine 328
Engine at Ohio State University 255
Equipment used in Nebraska tractor 391
Exhaust gases from automobiles 295
Fatigue of metals being conducted 418
Flame movement at normal temperature and pressure 210
Four master wing sections 271
Friction and power in engine 232
Gasoline 219
Impact on trucks 17
Inspection and, in interchangeable manufacture 57
Lubricating oil 481
Nebraska tractor 278, 391
Petroleum products 219
Piston temperature 402
Power 256
Preliminary metal 151
Preparation of specimens of metal 150
Propeller 477
Results of automobile exhaust gases 298
Results of tractor 392
Roads at Camp Humphreys 340
Thick wings with flaps 271
Torsional strength of multiple-splined shafts 129, 440

Thermostat

Description of 120
Comparative tests 120
Third semi-annual gasoline survey 365
THORPE, J C, ON SOME CONSIDERATIONS IN TRACTOR SERVICE 540, 598
Threaded Parts Division, S A E, personnel 200
TICE, P S, ON INTAKE FLOW IN MANIFOLDS AND CYLINDERS 282
Time-value cargo classification 596
Timing, ignition 557

Tire and Rim Division, S A E

Report at annual meeting 189
Result of letter ballot 382

Tires

Change in sizes 14
Cleveland meeting 14
Development of standards 14
Effect of sizes 168
Interchanging front and rear pneumatic, on trucks 15
Limits for oversize 15
Metric sizes 15
Motor vehicles 507
Tools, modern machine 202
Torque curves 157
Torsional strength of multiple-splined shafts (C W Spicer) 129, 440

Tractor Division, S A E

Personnel 200, 291
Report at annual meeting 189
Result of letter ballot 382
Subjects assigned 604
Tractor on corn-belt farms 511
Tractor show, S A E exhibit at Columbus 281

Tractors

Anti-freezing solutions 277
Belt work 277
Commercial aspect 541
Comparative cost of horses and 488
Corn-belt farms 511
Data on Illinois 487
Developing an alcohol engine 328
Equipment used in tests 391
Fuel consumption 393
Gun-mounts 377
Heavy 376
Nebraska, tests 278, 391
Number of days used 487
Repairs 488
Replacement of horses 487
Results of tests 392
Some considerations in service 540
Supply and maintenance 376
Trend of design 279
Weak spots 394
Trade balance 56
Trade, United States foreign 390

Traffic and Transportation

Aerial, as a business proposition 347
Aerial transportation of the immediate future 423, 593
Air and the business man 563
Commercial aviation in the eastern hemisphere 422
Conference on regulation 305
Development of commercial aerial service 349
Different countries 605
Fundamental factors of aerial 593
Grand Central Terminal 70
Highway 390, 562
Highway traffic regulations 53
Impediments to commercial air 565
Inherent value of speed 595
Pavements, heavy 480
Proposed remedies for accidents 486
Reliability of air service 347
Safety lessons for automobile drivers 12
Some inland and waterway problems 59
Street traffic in London and New York 10
Time-value cargo classification 596
Transmission lubricant and cup grease 221
Transmission lubricant specification 221

Transmission Division, S A E

Activities 382
Personnel 291
Subjects assigned 604

Transmissions

Design of, and axle gears 390
Developments in 350
Epicyclic gears 355
Gearbox design 352
Power efficiency 552
Rear-axle design 357
Universal-joint 352
Transportation arrangements for summer meeting 294, 389
Transportation in different countries 605

Treasurer's Report, S A E

At annual meeting 77
At April council meeting 603
At December council meeting 11
Truck and tractor meeting at Chicago 205

Truck Division, S A E

Activities 382
Personnel 200, 291, 294
Report at annual meeting 189, 191
Result of letter ballot 382
Subjects assigned 12

Trucks

Acceleration test of steam 159
Application of steam power to 155, 601
Engineering analysis applied to selling 600
Impact tests on 17
Interchanging front and rear pneumatic tires on 15
Trunk highways 64
Tunnel, National Advisory Committee's 5-ft wind (F H Norton) 489
Turbulence (H L Horning) 579

Turbulence

Characteristic in typical cylinders 584
Effect on flame propagation 579
Historical 579
Influence of, on flame movement 212
Methods for measuring 585
Residual 529
Two methods of producing 582
Two classes of aerial service 347
Typhoon received two knockdowns 316

U

Ultimate highway 166
Underlying principles of electrical ignition (B F Bailey) 570
United States Air Mail survey flight 134
United States foreign trade 390
Universal-joint and gearbox design 352
UPSON, R H, ON AERIAL TRANSPORTATION OF THE IMMEDIATE FUTURE 423, 593
Utilization of present automotive fuel (F C Mock) 26
UTZ, J G, ON ENGINEERS PLACE IN AUTOMOTIVE INDUSTRY 504

V

Valuation of railroads 69
Valve-steel specifications 513
VAN RANST, C W, ON HIGH-SPEED ENGINES OF SMALL PISTON DISPLACEMENT 368
Vaporizer, fuel 105
Variable factors in highway design (H E Breed) 238, 425
Variation in voltage and current 320
Variations in street temperatures 121
Varying the number of plies in plywood 486
Vehicular tunnel, automobile exhaust gases and ventilation 295, 450
Ventilation, automobile exhaust gases and vehicular-tunnel 295, 450

Vibrations

Causes and types of engine 55
Elimination of, due to synchronism 55
VINAL, G W, ON INSTANTANEOUS CURRENT AND VOLTAGE VALUES IN A BATTERY 319
VINCENT, J G, ON ECONOMY AND PERFORMANCE DEMANDS 440, 507
VINCENT, J G, ON ENGINEER'S PLACE IN AUTOMOTIVE INDUSTRY 505
Vincent, J G, presidential address 95
Volatility of internal-combustion engine gasoline (F A Howard) 145, 449

Volatility

Measurement of 146
Physical meaning 146
Requirements for full utilization of inherent 146
Voltage regulation in lighting plants 38
Voltage values in a battery, instantaneous current and (G W Vinal and C L Snyder) 319
Volumetric efficiency 122
Volumetric proportions of a combustible mixture 145

W

WALKER, K F, ON AUTOMOTIVE RADIATORS 127
War and commerce 94
War, effect on agriculture 506
WARNER, E P, ON COMMERCIAL AVIATION IN THE EASTERN HEMISPHERE 422

Water consumption in an automotive engine 158
Water power 17, 118
Water-power development 416
Weather and navigation aids 567

Weight

Can automobile body be reduced 285, 432
Consequential advantages of reduction in automobile 396
Limitation in automobile-body reduction 286
West Baden meeting 389
What is a machine tool 346
WHITE, A E, ON RESEARCH THE BOND BETWEEN THE UNIVERSITY AND INDUSTRY 497
WILLIAMS, W E, ON HIGHWAY-ROAD CONSTRUCTION 163, 425

Wind Tunnel

Airplanes tested 495
Balance used 491
Building and 489
Manometer in 493
Power plant 490
Special apparatus used 492

Wings

Experiments on thick, with flaps 271, 380, 421
Four master sections 271
New designs 274

Wood

Comparison of ordinary, with plywood 480
Seasoning for automobile bodies 404
WOODBURY, C A, ON NATURE OF FLAME MOVEMENT IN A CLOSED CYLINDER 209, 449
WOODWARD, R W, ON HIGH-TEMPERATURE PROPERTIES OF WHITE-METAL BEARING ALLOYS 149
WOOLSON, L M, ON PACKARD FUELIZER 240
World debt and paper currency 229
World's production of petroleum in 1920 349
Worm-gear design 358

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Vol. VIII JUNE, 1921 No. 6

INDEX

Activities of the Sections		605
Addresses at the Farm Power Dinner		588
Aerial Transportation of the Immediate Future—R H Upson		593
Air Transportation and the Business Man—V E Clark		563
American Technical Schools		592
Applicants for Membership		609
Applicants Qualified		608
April Council Meeting		603
Automobiles Aid All Occupations		539
Current Standardization Work		606
Cylinder Actions in Gas and Gasoline Engines—Sir Dugald Clerk		523
Discussion of Papers at the Chicago Truck and Tractor Meeting		598
Elements of Automobile Fuel Economy—W S James		543
Highway Transport		562
Highways		542
Index		611
International Ball Bearing Standardization—R S Burnett		577
March 1921 Issue of Data Sheets		542
Obituaries		604
Personal Notes of the Members	Adv Section	2
Radio Control of Ships		587
Research Work on Gears Needed		539
Some Considerations in Tractor Service—J C Thorpe		540
Summer Meeting		517
Transportation in Different Countries		605
Turbulence—H L Horning		579
Underlying Principles of Electrical Ignition—B F Bailey		570
Men Available	Adv Section	50
Positions Available	Adv Section	62

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Two large and modern forge shops to protect your schedule.

The knowledge of forging gained by 38 years of experience.

Laboratories and Engineering Departments to assist you with improvement or development work.

There is no substitute for QUALITY

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The CRANKSHAFT MAKERS

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Worcester, Mass.

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GUIDED
by facts, not theories
by performance records, not claims
by experience, not prophecy. Every
consideration points straight to KERITE
for permanently satisfactory and economical service.

KERITE INSULATED WIRE & CABLE COMPANY
NEW YORK CHICAGO

Rome-Wire

AUTOMOBILE

Ignition, Lighting, Starting and Battery Cables

For any kind of gas engines used with an electrical ignition system.

Our product:

(A) Primary and Lighting Cables,
(B) Secondary Cables,
(C) Starter Cables,
(D) Battery Cables.

The selection of construction offered in our standard product affords a choice of insulating and protective properties from which the buyer can satisfy almost any preference. In addition, we are in a position to make special cables, when desired, and particular attention is given to cables manufactured according to the customer's private specifications.

ROME WIRE COMPANY
Diamond Branch
Buffalo, N. Y.

Personal Notes of the Members

Items regarding changes in business connections, promotions, etc., are desired from the membership for insertion in these columns. This will enable members to keep their friends informed of their whereabouts and will also assist in keeping the records of the Society up to date.

John R. Aude has resigned as service manager of the Maxwell-Chalmers Co., Brooklyn, N. Y., to accept a position as automobile engineer of the Pabst Corporation, Milwaukee, Wis.

William B. Barnes, who was assistant in the experimental laboratory of the Cadillac Motor Car Co., Detroit, has severed his connection with that organization and accepted a position as assistant to the chief engineer of the Wheeler-Schebler Carbureter Co., Indianapolis.

R. E. Benner has become associated with George C. Goethals, 40 Wall Street, New York City, as engineer. He was formerly vice-president of the Hale & Kilburn Corporation, Philadelphia.

O. C. Berry, formerly research engineer of the Hupp Motor Car Co., Detroit, has become chief engineer of the Wheeler-Schebler Carburetor Co., Indianapolis.

Wallace B. Blood has been appointed director of sales and advertising of the Ray Battery Co., Ypsilanti, Mich. He will remain with the Campbell, Blood & Trump Co. of Detroit, of which organization he was vice-president, in an advisory capacity.

George C. Brainard has been elected vice-president of the Hydraulic Steel Co., Cleveland, which office he will hold in connection with that of general manager of the company.

George T. Briggs, who until recently was connected with the automotive department of the Sinclair Refining Co., Chicago, has been appointed general manager of the Motorcycle and Allied Trades Association, with headquarters at 326 West Madison Street, that city.

C. S. Bristow has been made manager of the Bristow Engineering Co., Portland, Ore. He was previously an engineer for the J. I. Case Plow Works Co., Racine, Wis.

Porter A. Buck, formerly assistant engineer for the Power Truck & Tractor Co., Detroit, has accepted a position as chief engineer for the Parcel Industries, Alpena, Mich.

Morris C. Burnside, until recently factory manager for the Anderson Forge & Machine Co., Detroit, has been appointed general manager of the National Engineering Products Co., Detroit and Dallas, Tex.

E. J. Butler has accepted a position with the Eaton Axle Co., Cleveland. He was formerly assistant engineer for the Freeman Motor Co., also of that city.

Robert H. Campbell is now associated with the Farmers Mfg. Co., 105 Scarritt Building, Kansas City, Mo., as vice-president, having resigned as vice-president of the Comet Automobile Co., Decatur, Ill. The Farmers company has taken over the interests of the Coleman Tractor Co., formerly of Kansas City, and expects to resume the production of the Coleman tractor in the near future.

H. I. Crow and F. Leroy Hill have organized the Motive Products Co., 604 Mission Street, San Francisco. Mr. Crow was formerly chief engineer for the Fageol Motors Co. of Ohio, Cleveland.

(*Continued on page* 4)

DIXON'S No. 677 Gear Lubricant

We have called attention to the fact that a gear box lubricant, to do effectively the work for which it is intended, must show minimum power losses in both hot and cold weather.

Tests conducted in our Mechanical Laboratory prove that *at freezing temperature the average gear lubricant will consume at least three times as much power as will Dixon's No. 677*. The average gear lubricant at freezing temperature stiffens to such an extent that the shifting of gears becomes quite a difficult matter. With Dixon's No. 677, however, gear shifting is accomplished as easily as in midsummer.

On a hot summer day the average gear lubricant becomes limpid and leaks through the packings, while Dixon's No. 677 retains its original plastic condition.

The ability of Dixon's No. 677 to withstand extremes of heat and cold results not only in an actual reduction of the power-loss in gear boxes, but also eliminates added strains to which all working parts of a car are subjected when the lubricant is either too hard or too fluid.

JOSEPH DIXON CRUCIBLE CO., Jersey City, N. J.

D X N Makers of Quality Lubricants—Established 1827 D X N

For Spur and Bevel Gears
Use DIXON'S No. 677
GEAR LUBRICANT

For Worm Drives
Use DIXON'S No. 675
GEAR OIL

SAVE FUEL SAVE OIL

BESSEMER MOTOR COMPANY

515 N. Nineteenth Street. Phone 51

Automobiles, Tires, Storage Batteries and Repairs

Michelin Tires and Tubes

Bessemer, Ala.,

Sept. 9, 1920.

The Ever-Tyte Piston Ring Co.,
St. Louis, Mo.

Gentlemen:

We are convinced that Ever-Tyte Piston Rings are the very best piston rings on the market.

We worked with an Oldsmobile at different times for two years trying all the so-called leak-proof piston rings without stopping the oil-pumping and finally used The Ever-Tytes as the last resort. The oil-pumping stopped and the machine is giving the best of satisfaction.

We tried three different makes of so-called leak proof rings in a Scripps-Booth car. Ever-Tyte Piston Rings again solved our problem and we are boosters for your product.

With best wishes for your continued success, we are,

Very truly yours,

BESSEMER MOTOR COMPANY.

Per ..... Mgr.

ZELNICKER *Ever-Tytes* are working such wonders daily because of their three piece, interlocked, flexible construction. They hug the cylinder walls tightly, even though slightly out of round. They make reboring of worn cylinders unnecessary.

TRY THEM AT OUR RISK

EVIDENCE BOOKLET SENT ON REQUEST

EVER-TYTE PISTON RING DIVISION

WALTER A. ZELNICKER SUPPLY COMPANY

1600 Kingsland Ave. (Wellston) ST. LOUIS

PERSONAL NOTES OF THE MEMBERS

Continued

H. D. Dabney has severed his connection with the National Association of Motor Truck Sales Managers, Detroit, where he held the position of executive secretary. His future plans have not been announced as yet.

L. R. Davis has become associated with the United States Rubber Co., New York City. He was formerly development engineer for the Revere Rubber Co., Providence, R. I.

C. E. Dickey has resigned as general manager of the Hammond Steel Co., Syracuse, N. Y., and will devote his entire time in the future to the Dickey Steel Co., 233 Broadway, New York City, of which he is president.

I. C. Dickover, formerly engaged in compiling repair parts catalogs for the Kleiber Motor Truck Co., San Francisco, has opened a catalog service at 288 Ninth Street, in that city.

Arthur Dugrey has resigned as superintendent of the carbureter plant of the Ford Motor Co., Detroit. He has not announced his future plans as yet.

Charles A. Erickson has resigned as general manager of the Standard Radiator Co., Springville, N. Y., and has accepted a similar position with the Sterling Radiator Co., Cleveland.

P. J. Eubanks after serving as chief engineer and manager of the Aero Products Co., Cleveland, for two years has resigned. In the future he will devote his entire time to the duties of chief engineer of Rush & Eubanks, a firm of consulting engineers with offices at 806 Engineers' Building, that city.

R. J. Fitness has resigned as consulting engineer and manager of the Detroit office of the Intercolonial Export Agencies, Montreal, Canada, and has accepted a position as assistant chief engineer for the Handley-Knight Co., Kalamazoo, Mich.

Clarence M. Foss has severed his connection with the Willys Corporation, Elizabeth, N. J., where he was service manager, and has become sales engineer for the Walker M. Levett Co., 417 East 23rd Street, New York City.

R. G. Garretson, formerly engineer for the Clark Tructractor Co., Buchanan, Mich., has accepted a position as chief engineer for the Bryan Harvester Co., Peru, Ind.

R. C. Greiner, until recently chief engineer for the U. S. Tractor & Machinery Co., Menasha, Wis., is now engaged in the practice of mechanical engineering at Minneapolis, Minn.

Morris A. Hall, formerly secretary and treasurer of the Gallon-Hall Corporation, and editor of *Automotive Engineering*, New York City, has been elected president of the International Cultivator Corporation, successor to the Termaat-Monahan Mfg. Co., Oshkosh, Wis.

O. D. Heavenrich has accepted a position as engineer for the Apex Motor Corporation, Ypsilanti, Mich.

Joseph Husson, formerly editor of *Commercial Vehicle*, 239 West 39th Street, New York City, has been appointed general sales and advertising manager for the Northway Motors Corporation, 1 Beacon Street, Boston.

Harry E. Jenkins has been appointed sales agent of the U. S. Cartridge Co., Lowell, Mass. He was formerly sales manager and engineer for the Universal Products Co., Detroit.

S. S. Jenkins, who was formerly Detroit district manager of the Bijur Motor Appliance Co., Hoboken, N. J., has been appointed general sales manager with offices at the factory.

Carl E. Johnson, who was previously a designer for the Standard Sanitary Mfg. Co., Louisville, Ky., has become associated with the Delco Co., Dayton, Ohio, in the same capacity.

R. P. Johnson, vice-president and general manager of the Warner Gear Co., Muncie, Ind., was elected first vice-president of the American Gear Manufacturers Association at its fifth annual convention recently held in Cincinnati.

(*Concluded on page* 6)

What Was the Motive of Your West Baden Meeting?

In the five days from May 24 to May 28 over six hundred of the leading automotive engineers of America—all of them S. A. E. members—met in professional and recreational conclave at the West Baden Springs Hotel, West Baden, Indiana.

What was the motive behind this meeting?

It is true that aviation, farm transportation problems and pure engineering topics were analyzed and discussed. But weren't the important papers of your meeting most concerned with the individual motorist—the man who owns and drives his own car?

For, after all, it is the motorist who has made the automotive industry what it is today. Trucks, tractors and aeroplanes we will have in increasingly large numbers, but the very foundation of automotive endeavor is the passenger car itself.

MoToR, the National Magazine of Motoring, fully appreciates the efforts of you engineers to build better motor cars, and this magazine closely follows your footsteps by aiming to teach people how to make better use of them, both from a utility and mechanical standpoint.

We believe that the automotive engineer who reads MoToR regularly will be just a little more efficient because this magazine portrays so faithfully the ideals and ambitions of the man who ultimately receives greatest benefits from the great work you are doing—the individual motorist.

MOTOR

119 West 40th Street **New York, N. Y.**

Where Power Meets Weight

Whir!

The motor of the big truck gathers its full strength for the getaway.

In goes the clutch, and the full power of sixty horse meets the dead weight of many tons —at the exact point where the teeth of two gears meet and mesh, *in the transmission.*

The great carrier fairly leaps into motion and is off again on its day's work.

And the gears? Such work has been little more than play for them—if they are Covert-built.

For Covert gears, so thousands of truck, tractor and passenger car owners will tell you, are proof against every strain that use can impose upon them.

See to it that Covert Gears—the exclusive equipment of Covert Transmissions—are parts of your next automotive investment.

COVERT TRANSMISSIONS

COVERT GEAR COMPANY, INC.

Sales, Engineering and Factory: Lockport, N. Y.
Export Offices: 100 Broad Street, New York City

PERSONAL NOTES OF THE MEMBERS

Concluded

W. A. Jordan has been elected president of Jordan & Co., 305 Broadway, New York City. He was formerly vice-president of the United Motors Service, Inc., Detroit.

Charles C. Kavanaugh has opened a garage at 6 Dugan Street, Sumter S. C. He was formerly service manager for the Jennings-Burkett Motor Co., also of that city.

Crosby King, formerly layout man and designer for the Superior Truck Co., Atlanta, Ga., has joined the engineering department of the Vim Motor Truck Co., Philadelphia, Pa., in a similar capacity.

N. L. Lieberman, general manager of the New Jersey Brass Foundry, Bayonne, N. J., has become associated with J. P. Davies & Co., 1819 Broadway, New York City, specializing in the development, manufacture and sale of automotive equipment.

William E. Metzger, who was formerly vice-president of the Columbia Motors Co., Detroit, has been elected president of the Wills Sainte Claire Co. of Michigan with headquarters at Woodward Avenue and Grand Boulevard, Detroit.

D. Bruce Morgan has not resigned as consulting engineer of the Paquit Ignition Corporation as stated in the May issue of THE JOURNAL. He is engaged in consulting engineering work for various companies including the Paquit corporation and is located at 1819 Broadway, New York City.

Frederick P. Nehrbas has been appointed works manager of the Weidely Motors Co. of Indianapolis. He was until recently a vice-president and general manager of the Premier Motor Corporation, also of that city.

Nelson B. Nelson, formerly superintendent and chief engineer for the Kardell Tractor & Truck Co., St. Louis, and for the past 12 years connected with tractor engineering, has become associated with the New Departure Mfg. Co., Bristol, Conn., and will have charge of engineering at its Chicago office.

Robert B. Porter has severed his connection with the American & British Mfg. Corporation, Bridgeport, Conn., where he was motor-car engineer, and has joined the sales force of the Sherwood Automobile Corporation, 1129 Atlantic Avenue, Brooklyn, N. Y.

L. F. Seaton has been appointed efficiency and purchasing engineer for the University of Nebraska, Lincoln, Neb. He was formerly chief engineer of the Patriot Motors Co., Havelock, Neb.

S. Ward Seeley has resigned as service and publicity manager of the General Motors Acceptance Corporation, 120 West 42nd Street, New York City. No announcement regarding his plans for the future has been made.

J. C. Slager has accepted a position with the International Time Recording Co., Endicott, N. Y. He was formerly chief designer of the Recording & Computing Machines Co., Dayton, Ohio.

Herbert C. Snow has resigned as chief engineer of the Winton Co., Cleveland, Ohio, to accept a similar position with the R. H. Long Co., Framingham, Mass.

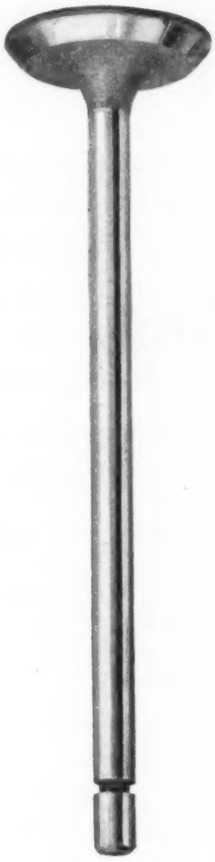
Milton G. Sohn holds the position of civil enginer in the City of Stockton, Cal. He was previously plant engineer for the Redwood Manufacturers Co., Pittsburg, Cal.

John Springer, vice-president and engineer for the Dickinson Cord Tire Corporation, New York City, has resigned and is now located at Farmingdale, N. J.

G. A. Ungar, formerly vice-president of the Engineering & Commerce Corporation, New York City, has been selected by the American Bronze Corporation, Berwyn, Pa., to take charge of its newly established engineering bureau. This bureau will, it is planned, devote its time to a full study of plain bearings, including the collection of authentic data and the conduct of original research work regarding the design, installation, lubrication and maintenance of this type of bearing.

The Steel Products Company

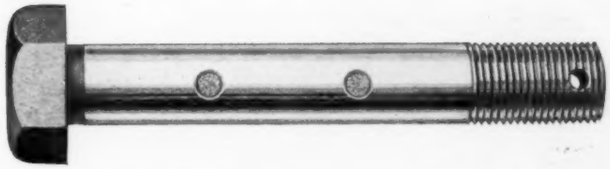
Engineering and Manufacturing Service



Investigation by men who are daily observing the operation of valves, tappets, king bolts, spring bolts, and drag links under various conditions often results in the suggestion of a proper material for a specific purpose—and is based on the knowledge of results actually obtained in cases where similar problems have been presented and solved.

Possibly investigation indicates a condition which has previously been met by change of design or heat treatment.

In other words, the information obtained by our engineers in solving the many problems presented to them may be so applied through proper recommendations as to save time and expense which would be lost if our customers did not take advantage of the knowledge and data accumulated through years of experience in production of parts which have proven satisfactory.



The Steel Products Co.

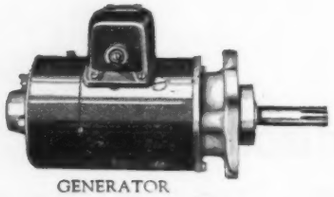
MAIN PLANT	MICHIGAN PLANT	BOLT and SCREW PLANT
Cleveland	*Detroit*	*Cleveland*
VALVES	DRAG LINKS	CHASSIS BOLTS
TAPPETS	ROD ASSEMBLIES	SPECIAL BOLTS
SPRING, KING AND	STARTING CRANKS	CAP SCREWS
TIE ROD BOLTS	ETC.	ETC.

ATWATER KENT

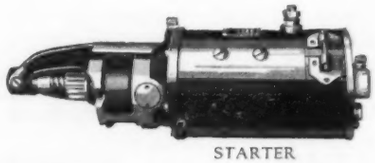
Ignition, Starting and Lighting

Atwater Kent equipment is manufactured to the highest standards of accuracy and precision and truly reflects the personality and ideals of the founder of this business—to make and market a product as good as material, experience and the most exacting workmanship can make it.

Atwater Kent Starting and Lighting is standard equipment on the New Packard Single Six.



GENERATOR



STARTER

An able engineering corps at your service

ATWATER KENT MFG. COMPANY *Philadelphia*

To make your shop produce more at less cost—

with heat-defying wear-resisting Stellite Tools

Fully explained with complete illustrations, charts and detailed instructions.

Compiled in text-book form for the first time. Note the convenient pocket size.

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Newly developed Stellite Practice—
Assures Large Savings and 25 to 150 Per Cent Increases in Production!

First Time in Print

Get these two new books!

EATON

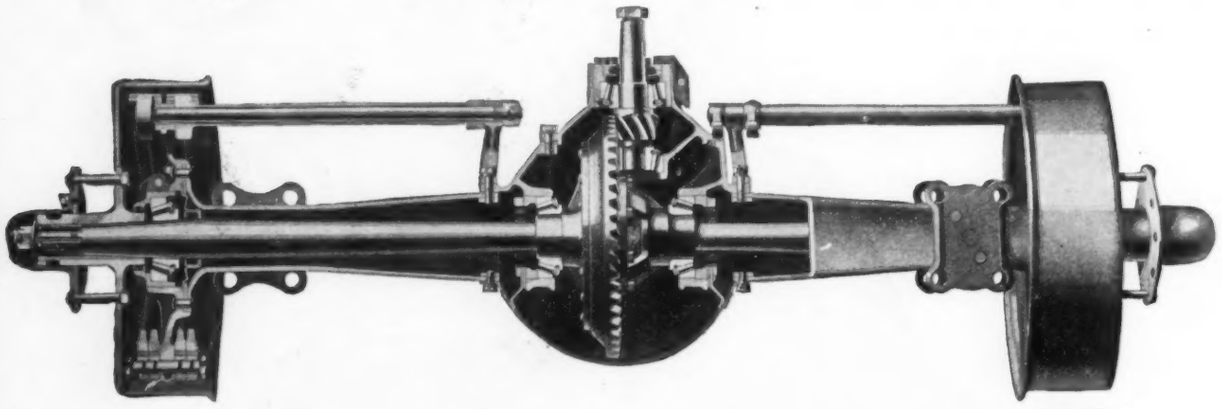
TRANSPORTATION TODAY DEMANDS of its servants greater efficiency and economy, and it is only logical that the high-speed one-ton truck should be widely favored for the despatch of merchandise and farm products.

The swift hauling of a full one-ton load calls for an axle especially planned to deliver high engine torque, an axle made strong enough to stand smashing impact strains and light enough to give a minimum unsprung weight, and one having a reliable braking action.

Such is the Eaton One-Ton Bevel Gear Axle.

Serving under certain of America's finest high-speed one-ton trucks, this staunchly built Eaton product, with its durable drive and large brake drums, is giving an advanced order of axle performance.

On request, detailed drawings and complete specifications of this Eaton Model 1000 and its companion front axle will be placed in the hands of interested truck manufacturers or engineers.



THE EATON AXLE COMPANY, CLEVELAND, OHIO

DIVISION OF THE STANDARD PARTS COMPANY

OTHER DIVISIONS ARE: THE PERFECTION SPRING COMPANY, THE BOCK BEARING COMPANY, THE STANDARD WELDING COMPANY

AXLES

The buyer's market is here. It means intensive competition. A device that insures instant starting throughout the year—the greatest need of the automobile today—will be a vital factor in overcoming both competition and sales resistance.

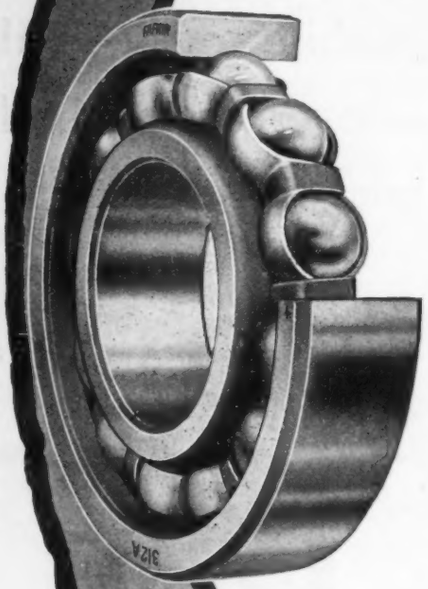
Master
ELECTRICAL PRIMER

Is a perfect starting device that has demonstrated its worth for years as standard equipment on quality cars. It insures starting within seven seconds in any weather. It saves time and gasoline. Less current used from battery with Master Electrical Primer than without it. And, too, it prevents flooding of the engine with raw gasoline, thereby eliminating crank case dilution and consequent piston, cylinder and bearing wear.

Master Primer Company
130 E. Larned Street **Detroit, Michigan**

Standard Equipment on Quality Cars

FAFNIR



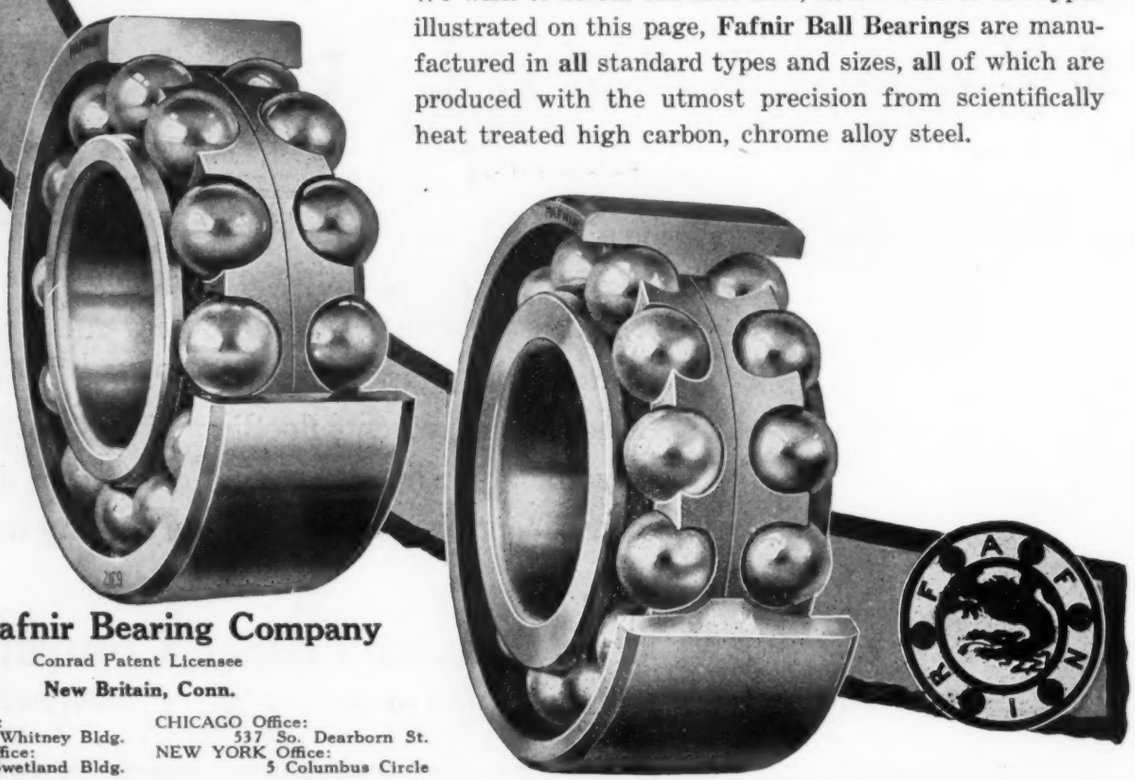
THREE types of **Fafnir Ball Bearings** are shown in the accompanying photographs.

The **single row Fafnir Radial Ball Bearing** is best in most cases involving radial load or radial load plus moderate end thrust load in one or both directions.

The **double row Fafnir Radial Ball Bearing** is advantageous when the details of construction are such as to require a bearing of minimum diameter without a sacrifice of load carrying capacity. For example, a ball bearing of this type would be just the thing to install back of a passenger car bevel gear drive pinion, in any case where the high speed of revolution and design of the surrounding parts of the mechanism require a ball bearing of great load carrying capacity and minimum diameter, and where the end thrust is not too heavy for a **radial** type of bearing.

The **double row Fafnir Radial-Thrust Ball Bearing** is useful for carrying radial load plus heavy end thrust load in one or both directions on a single ball bearing. For instance, a **Fafnir Ball Bearing** of this type is very useful in the case of a worm driven motor truck, for carrying the radial load at one end of the worm and also the extremely heavy worm thrust which is double acting, depending on whether the worm is in forward or reverse drive.

We wish to stress the fact that, in addition to the types illustrated on this page, **Fafnir Ball Bearings** are manufactured in **all** standard types and sizes, **all** of which are produced with the utmost precision from scientifically heat treated high carbon, chrome alloy steel.



The Fafnir Bearing Company

Conrad Patent Licensee

New Britain, Conn.

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CLEVELAND Office:
916-917 Swetland Bldg.
CHICAGO Office:
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INTERNAL COMBUSTION POWER UNITS BULLETIN No. 3

THE MATERIAL

Successful Power Units require a material that will retain the true shape imparted by careful workmanship and proven design, under wide variations of pressure and temperature.

Grey Iron has been generally accepted as the most practical material for Pistons, Piston Rings and Valves (cast heads with steel stems). There are, however, certain faults in this metal, as usually obtained, which must be eliminated before the manufacturers and users of Internal Combustion Motors will acknowledge this to be the ideal material. These faults are-

"Weakness, Brittleness, Porosity, Elastic and Too Hard, or Soft and Non-elastic, GROWING and WARPING with repeated heatings, Frequent Oxidation and Inconsistencies between the various heats."

Many metalurgists have, for some time, believed that these faults result from the method of making ordinary iron castings, rather than being characteristics of the alloy. The majority of the elements present, other than iron, being in reality impurities remaining from a melting process that is seldom, if ever, refining and generally the direct opposite.

The usual foundry practice in the United States produces, for Internal Combustion Power Units, an iron whose composition averages within the following limits-

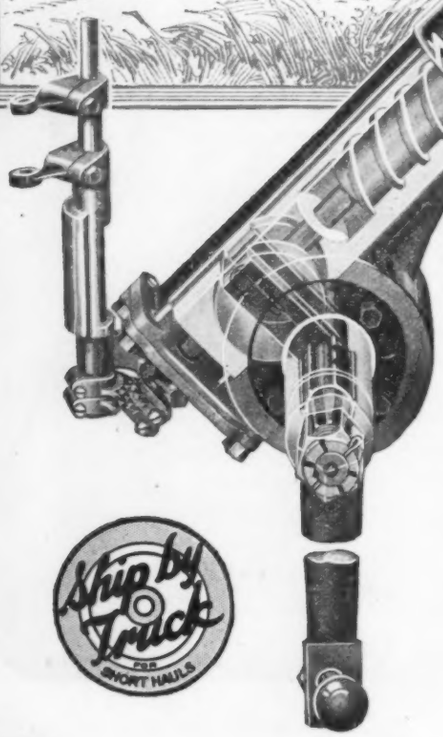
Silicon	1.75 to 2.25%
Sulphur	0.07 to 0.12
Phosphorus	0.60 to 0.85
Manganese	0.50 to 0.75
Combined Carbon	0.50 to 1.00
Graphitic Carbon	2.40 to 3.00
Total Carbon	3.00 to 3.50

A few foundries have better mixtures, a number work more closely and consistently, but the majority of reputable concerns are in the habit of furnishing grey iron analyzing approximately to these figures.

SEYMOUR LABORATORIED UNITS, INC.

W. E. SEYMOUR, President *"More Than a Manufacturing Corporation"* MILWAUKEE, WIS.

Detroit Sales and Warehouse Office, 1001 Book Building



Better Transportation
—The Nation's Vital Need

With rail facilities taxed to the breaking point, our biggest problem today is to relieve this strain and help transportation keep pace with industry and agriculture. Unquestionably the solution is the motor truck. Its worth has already been established, and the necessity for its use on a larger scale is becoming more and more apparent every day.

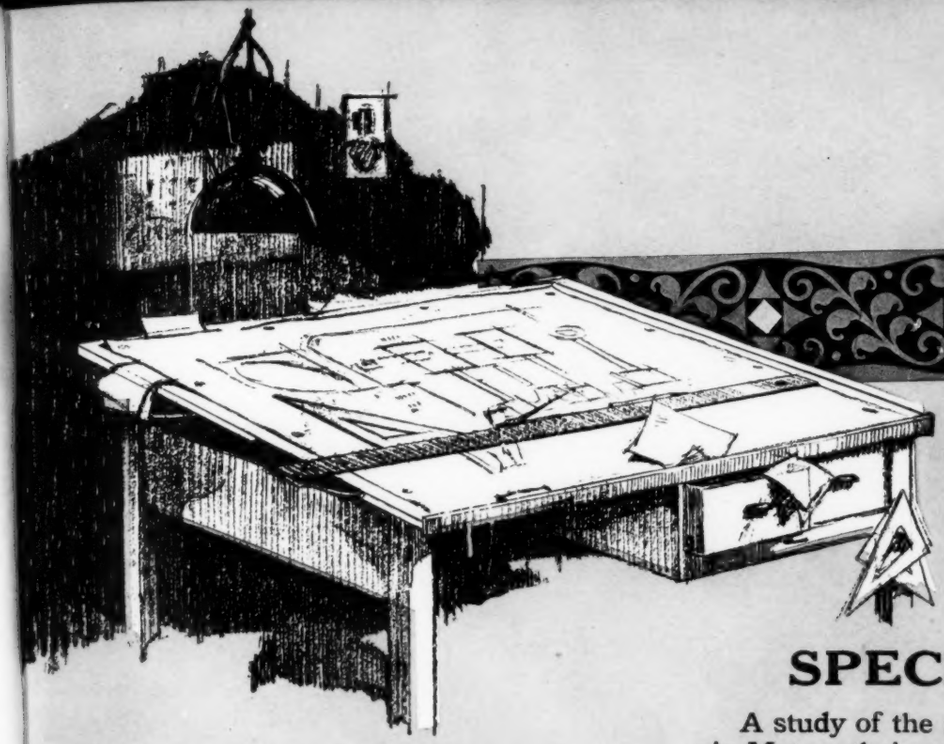
Ross Steering Gears have played an important part in making the motor truck a more efficient and reliable means of transportation. The easy steering, safety and reliability, which are guaranteed by the exclusive screw and nut design, have made Ross Steering Gears standard equipment on 455 different motor truck models from 178 different manufacturers.

Write for any further information desired

ROSS GEAR & TOOL COMPANY
8th and Heath Sts., Lafayette, Ind., U. S. A.

ROSS STEERING GEARS

THE STEERING GEARS THAT PREDOMINATE ON MOTOR TRUCKS



Wisconsin
CONSISTENT

SPECIFICATIONS

A study of the features that have given Wisconsin Motors their prominent place among truck and tractor power units, reveals the designer's great care to produce power plants for service beyond the accepted limits of good service.

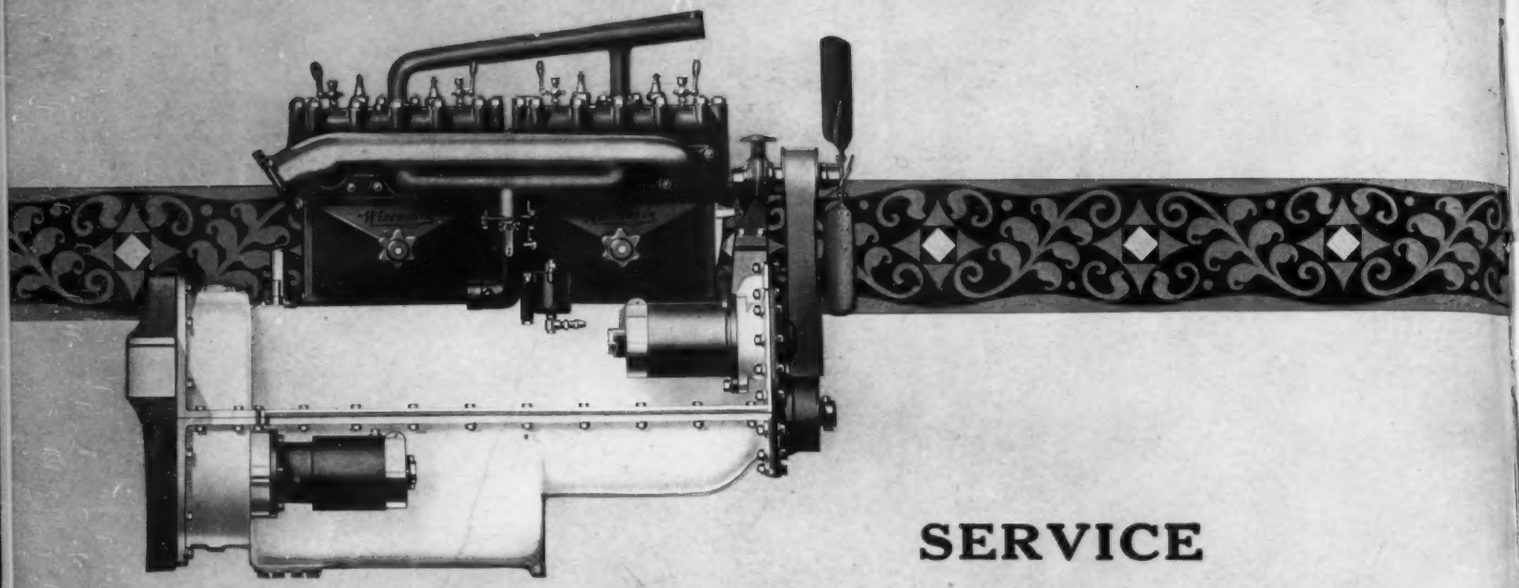
These special features will interest makers of trucks and tractors who wish to incorporate real quality into their product—who build to create reorders for their product—whose reputation is built into every vehicle they sell.

Wisconsin practice is perfected to support the truck and tractor builder in every statement he makes for his product. Our experience and assistance to many of the best known manufacturers has been the means of bringing them a steady flow of business.

Here are the points of Wisconsin construction that can help you in your marketing problems.

Aluminum crank case—Three point suspension—All steel supports—Chrome Nickle Crank Shaft—Force feed Lubrication—All bearings extra large bronze lined with babbitt metal—Tungsten steel exhaust valves—Wide fan gears—Rigid fan belt and drive—Special provision to prevent oil leaks—Combination inlet and exhaust valves—Valve stems and tappets automatically lubricated from crank chamber—Oil tight valve cover plates.

We shall be glad to detail any of these points upon request.



SERVICE

A well known figure in the industry, in addressing a dealer organization told them to "begin every line and sentence of your effort, and end every line with *"service."*

Service is all-important in keeping the truck owner sold. An hour or a day laid up because of inability to secure a necessary part will be remembered when occasion comes to talk about the purchase of another truck.

The Wisconsin Motor Manufacturing Company realizes the penalties for failure to keep a vehicle on the road. Accordingly, undivided attention is given calls for parts or service that the vehicle manufacturer cannot furnish.

This assistance to both the manufacturer and dealer is finding approval with fleet owners and with individuals. It is having its effect where the merits of trucks are discussed, and the good-will established by our efforts is helping sales to a very appreciable extent.

Wisconsin Motors make the truck last—
and one truck sells another.

WISCONSIN MOTOR MFG. CO.
MILWAUKEE, WIS.

Wisconsin
CONSISTENT

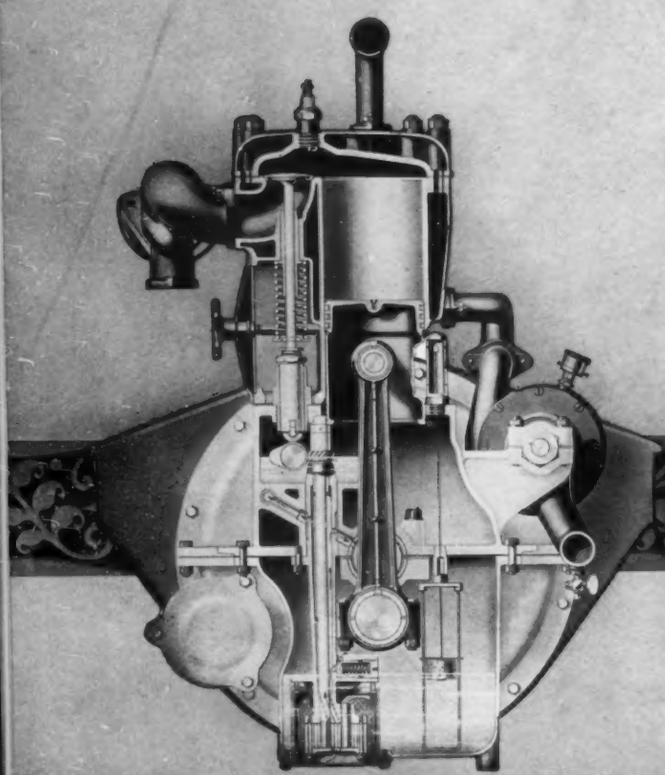
DISTRIBUTORS

T. M. FENNER
21 Park Row, New York City

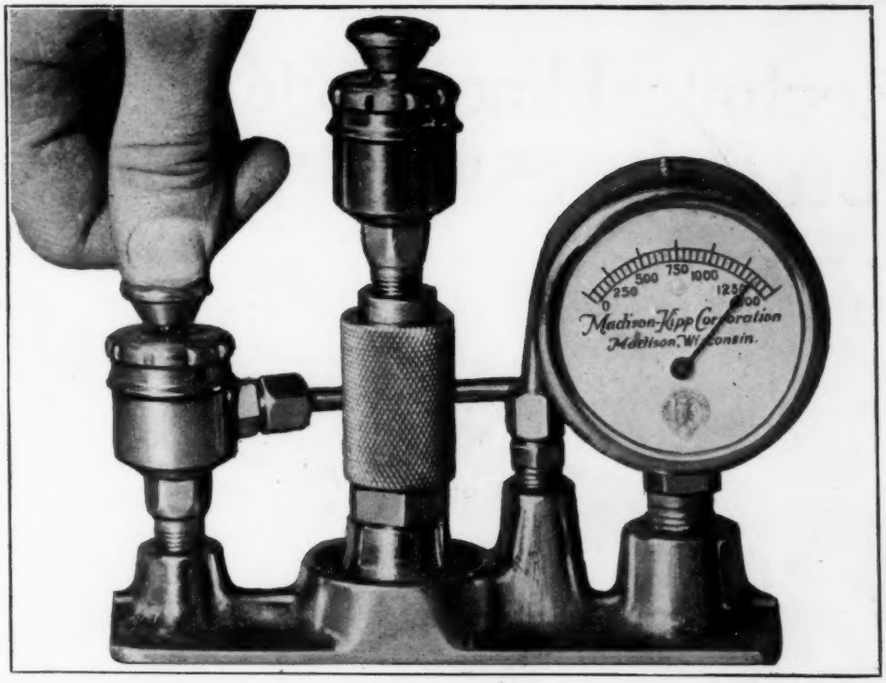
CHANDLER - HUDSON CO.
Seattle, Washington

WISCONSIN MOTOR PARTS CO.
2354 Cottage Grove Avenue
Chicago, Illinois

EARL P. COOPER COMPANY
1310 South Los Angeles Street
Los Angeles, California



S. A. E.



Pumps 1,200 pounds—and more
Convincing proof of the efficiency of Oil-Kipps

When we are asked to prove that Oil-Kipps actually force heavy oil around the bearing surfaces of steering spindles, shackle bolts, spring bolts and other points on the chassis requiring lubrication, we do this:

We attach an Oil-Kipp to a pressure gauge registering, say, 1,500 pounds. Then we pump the plunger and the dial begins to register—the needle passes 500 pounds, 1,000 pounds, 1,200 pounds, and more. It even exceeds the capacity of the gauge.

We do this on your own gauge, or on ours. We ask you to do it. We invite you to test any other device, using either grease or oil, in the same way—and we'll venture the prediction right now that Oil-Kipps will register more than twice the pressure.

Many engineers have long believed that oil is a more efficient lubricant than grease, but the problem was to find a way to use it for chassis lubrication. With the invention of Oil-Kipps by the Madison-Kipp Corporation—the largest manufacturers of motor lubricators in the world—the way has been found.

A recent analysis of a well known automobile grease revealed the presence of 68.5 per cent of lubricant and 31.5 per cent soapy, spongy "filler" which makes grease too heavy to penetrate into remote friction surfaces. In use, this "filler" clogs up drill holes and further impedes lubrication, resulting in worn and damaged bearings (see illustration), as in king bolt at left. Grease frequently contains acids and caustic which gradually eat away the metal.

What are Oil-Kipps?

Oil-Kipps are small repeating oil-pumps, accumulating a pressure of more than 1,200 pounds per square inch, which force heavy oil over the bearing surfaces where grease cannot penetrate. They are easy to operate—just pump the plunger a few times and the oil is forced all the way around the bearing. They are easy to fill—one filling provides twenty or more shots, enough for a month or longer.

With Oil-Kipps on the steering gear, it takes but a few seconds to pump an abundant supply of pure, fresh oil to the bearing surfaces where wear is heaviest.

The parts move freely, one upon another. Steering is made easy. Squeaks and rattles and excessive wear are eliminated.

We will gladly supply blue prints and detailed information about Oil-Kipps, also about the new Oil-Kipp force feed lubrication of the clutch release bearing. Write today.

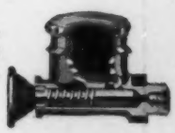
MADISON-KIPP CORPORATION,
Madison, Wisconsin

Vertical Oil-Kipps for steering knuckles and other vertical positions

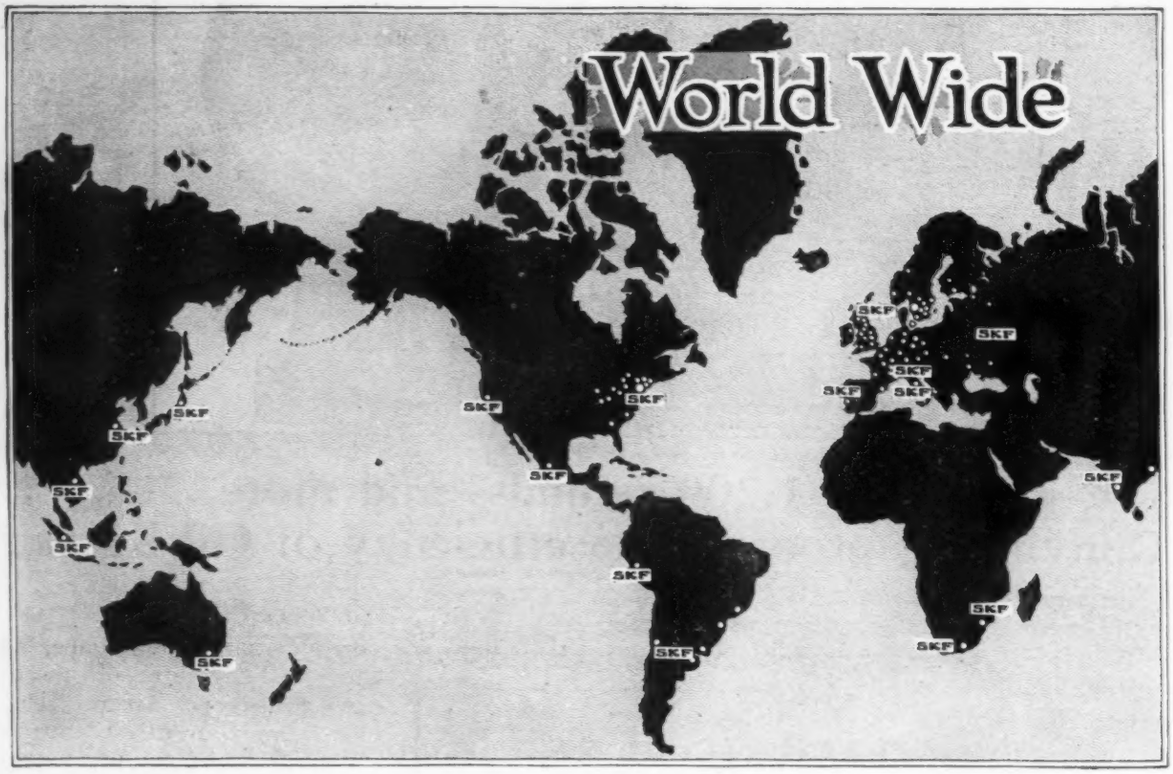
Oil-Kipps

SILENCE THE CHASSIS

Horizontal Oil-Kipps for spring bolts and other horizontal bearings



The technical knowledge that comes to you from SKF engineers is



as it is the sum of the data gathered by SKF organizations in all industrial countries.

This fund of engineering information we bring to the fabrication of all products bearing the mark SKF and the operation of those industries which we are requested to supervise. In order that complete reliance may be placed in the endorsement expressed by the mark SKF it is necessary not alone that we control and supervise each step in the manufacture of a product but also its final installation.

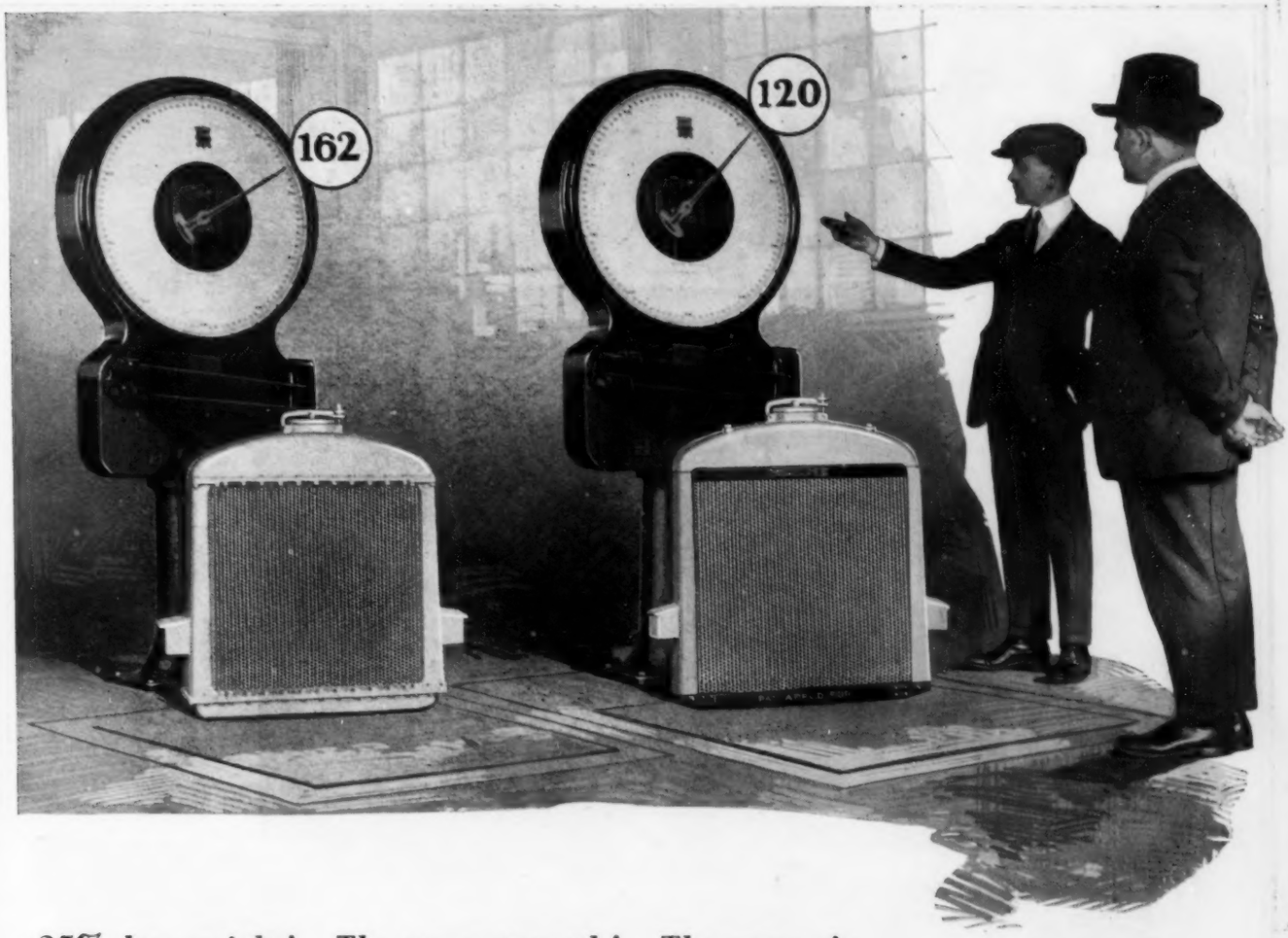
Because every effort is made to assure the most satisfactory use of products marked SKF we welcome requests for information concerning their proper application and maintenance.

Automotive manufacturers should feel that this technical knowledge is always available. You are urged to use it freely without any sense of obligation.

SKF Industries, Inc.
165 Broadway, New York City

Supervising at the request of the stockholders.
The Hess-Bright Manufacturing Co.
The Skayef Ball Bearing Co.
Atlas Ball Co.
Hubbard Machine Co.
SKF Research Laboratory

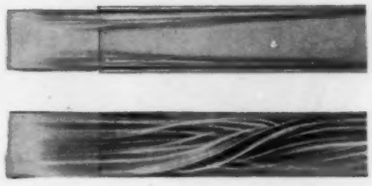
620



25% less weight! The same strength! The same rigidity! The same cooling!—all at less cost! This is what you get in Modine Suspension Core Construction!

The heavy, cast iron bottom tank is entirely dispensed with. Two small gaskets and four cap screws replace two large gaskets, four fastening bars and a mass of nuts, bolts and lock washers. Material, machining and assembly costs—all have been cut to a minimum in this new Modine method of constructing heavy duty radiators.

Modine Suspension Core Construction (Pat. applied for) can be obtained only with either a Modine Spirex or a Modine Tubular core—a combination which insures both manufacturer and purchaser the greatest possible cooling capacity per unit of total radiator weight.



The famous Spirex spiral provides maximum cooling. It maintains the colder air against the hot sides of the water channels. This assures the highest possible rate of heat transmission. Every cubic inch of air leaves the core saturated with heat. The Modine Spirex core can be furnished in any type of construction.

Modine Manufacturing Company

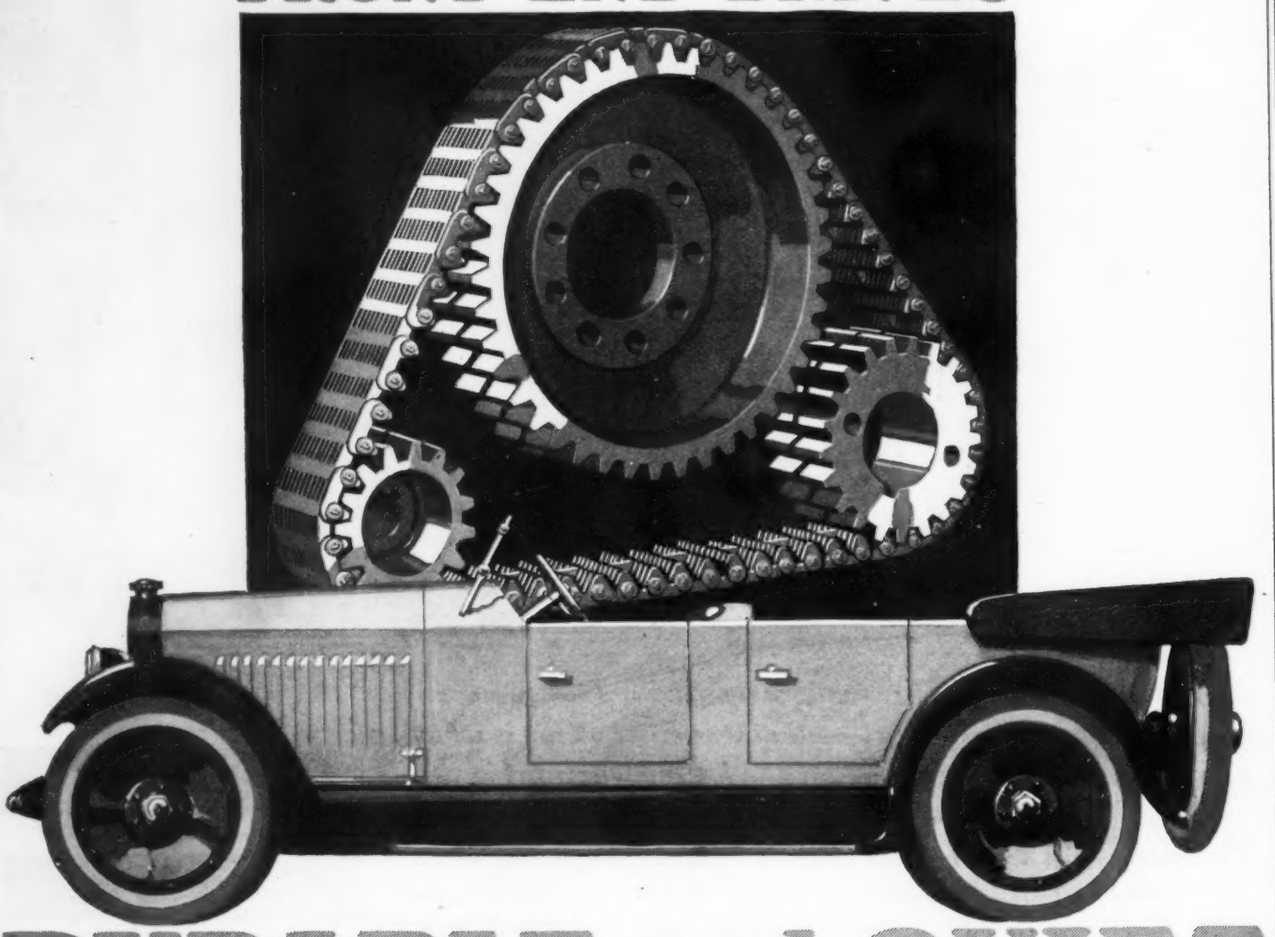
210 Sattley Bldg. **Racine, Wis.**

F. Somers Peterson
Pacific Coast Representative

San Francisco *California*

SPIREX MODINE RADIATORS TUBULAR MODINE RADIATORS

MORSE
FRONT END DRIVES



DURABLE and QUIET

Basing our predictions of the future on the constant healthy growth of the past in which our oldest customers are our present customers, we believe that the next cycle of changes in the automobile engine design will reveal the Morse Front End Drive used far in excess of any other known form of timing drive.

Write for latest list of factory equipped cars.

MORSE CHAIN COMPANY

MAIN OFFICE AND WORKS
ITHACA N. Y.

SALES AND ENGINEERING OFFICE
COR. EIGHTH & ABBOTT STS. DETROIT, MICHIGAN

Jefferson DROP FORGED Steel Wheels for Passenger Cars

Jefferson Drop Forged Steel Wheels are the result of co-ordinating two positively new principles of wheel making—Drop forging and Unit construction, producing

ONE PIECE

rugged, elastic steel wheels of greatest strength. Hub, brake drum, spokes and felloe are drop forged integral—no bolts, nuts, rivets, welds or joined sections.

LIGHTER THAN WOOD

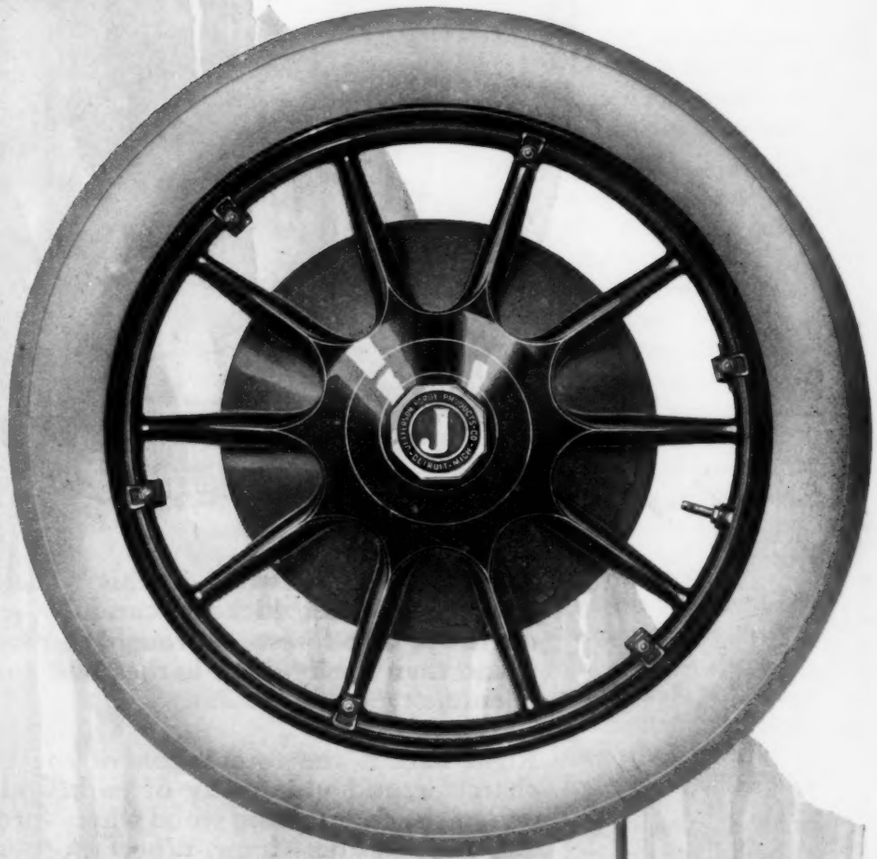
wire, or disc wheels of standard construction—unaffected by extreme heat, cold, dryness or dampness. They are

INDESTRUCTIBLE

and are guaranteed for the life of the car on which they are used—a positive assurance of safety, economy, and freedom from wheel annoyances. They are made by the same process as crank shafts, axles, steering knuckles, transmission gears and other motor car parts enduring constant pounding strains and stresses.

*"The hand of force * * * can not disjoin them"*

Th Jefferson



RUSSELL A. ALGER, *President*
FREDERICK M. ALGER, *Vice-Pres.*
CHARLES E. WADE, *Vice Pres. & Gen. Mgr.*
F. ARCHER HINCHMAN, *Sec'y & Treas.*

THE JEFFERSON FORGE PRODUCTS CO. DETROIT, (*Established 15 Years*)

EVERY piece of wood in this wheel is the highest grade hickory, carefully selected, cut in our own forests, thoroughly air seasoned —and then finally dried in the latest and most scientific type of dry kilns.

Right here is the foundation of the quality, character, and uniformity of each and every one of the four million wood wheels produced annually by the Motor Wheel Corporation.

MOTOR WHEEL CORPORATION - LANSING, MICH.

Motor Vehicle Wheels Complete — Metal Stampings — Steel Products

Makers of Gier **Tuarc** Steel Wheels

Motor Wheel
PRODUCTS

BAKELITE

REG. U. S. PAT. OFF.

A dental lamp MOULDED

Dentistry has made strides since the Egyptians plugged their teeth with copper, lead, or gold. Step by step the science has advanced, and for every new improvement a material has been found to make its application possible.

A lamp to provide proper illumination within the patient's mouth called for a material possessing an unusual combination of remarkable qualities. The deleterious action of saliva is well known: any lamp for the purpose must be acid and alkali proof. The sensitive tissues had to be protected from even the low heat generated by a small bulb; and this called for a perfect non-conductor. The absorption of moisture and germs would have made such a lamp useless: a high degree of denseness was essential. It is necessary that dental apparatus be frequently sterilized by boiling; a soluble substance would have made this impossible. And the material chosen had to be a non-conductor of electricity, to make practicable the manufacture of such a lamp.

Bakelite, moulded, has qualified in every respect. It resists acids and alkalis; it is a non-conductor of both heat and electricity; it is infusible, insoluble, and chemically inert. It may be moulded in practically any shape and size, incorporating metal inserts accurately in place. It is of extremely low porosity, has a specific gravity of 1.35, and maintains a high finish under all conditions.

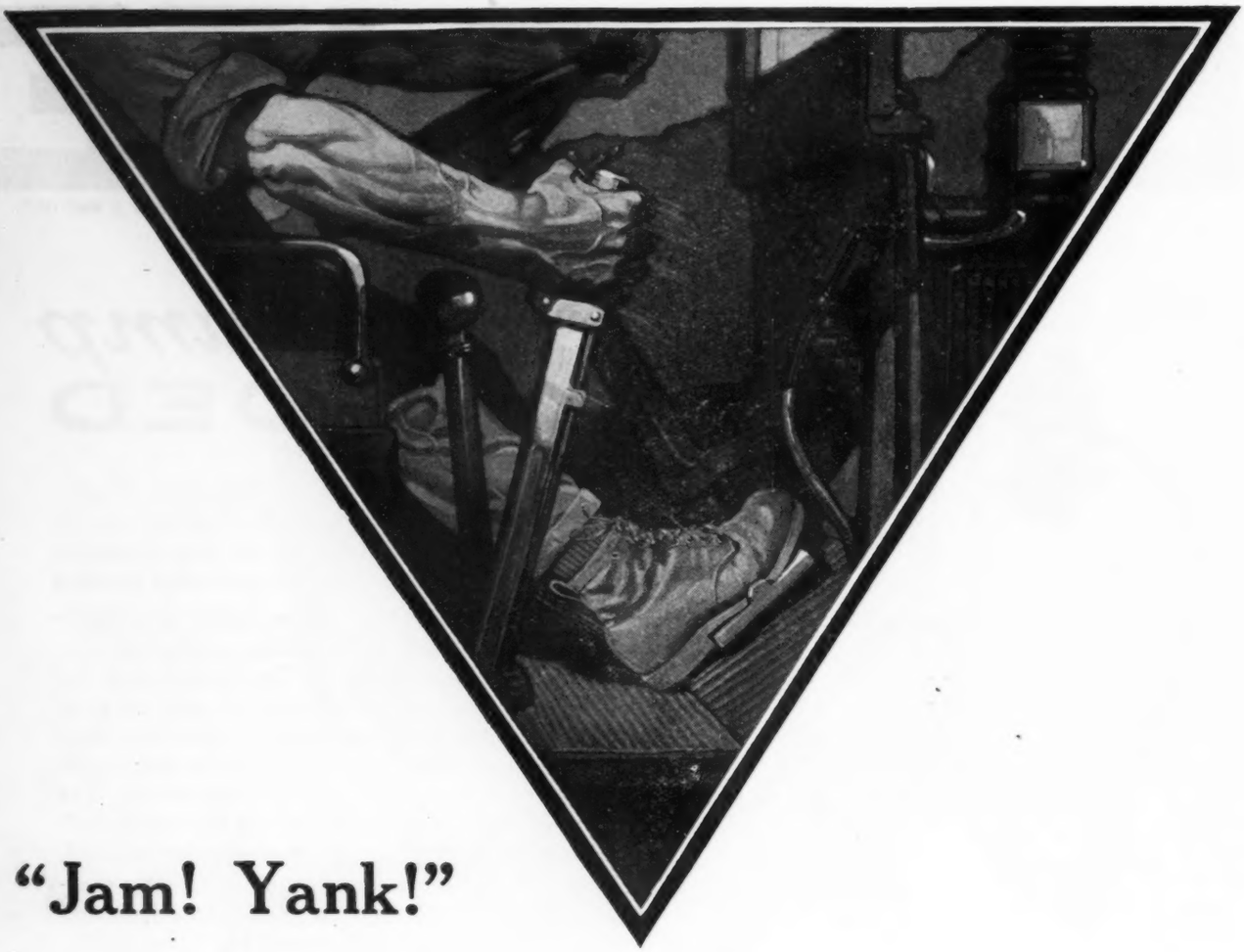
Bakelite has established itself in almost every industry. A phenolic condensation product, it provides manufacturers with a *new raw material,* capable of almost limitless application. Perhaps you could use it.

GENERAL BAKELITE COMPANY

TWO RECTOR STREET, NEW YORK, N. Y.

We welcome inquiries from manufacturers, and maintain a research laboratory for the working out of new applications.

2086-B



"Jam! Yank!"

Out with the clutch—
Down on the service brake—
Back on the emergency with all the force you've got!

* * * * * *

IT takes quick thinking and sound muscle to bring 10 tons of moving load to a stop—and it's no small job for the brakes.

Yet thousands of Timken Brakes are daily meeting the excessive demands of the emergency stop. Their quick, sure action is a safeguard to driver, truck and traffic.

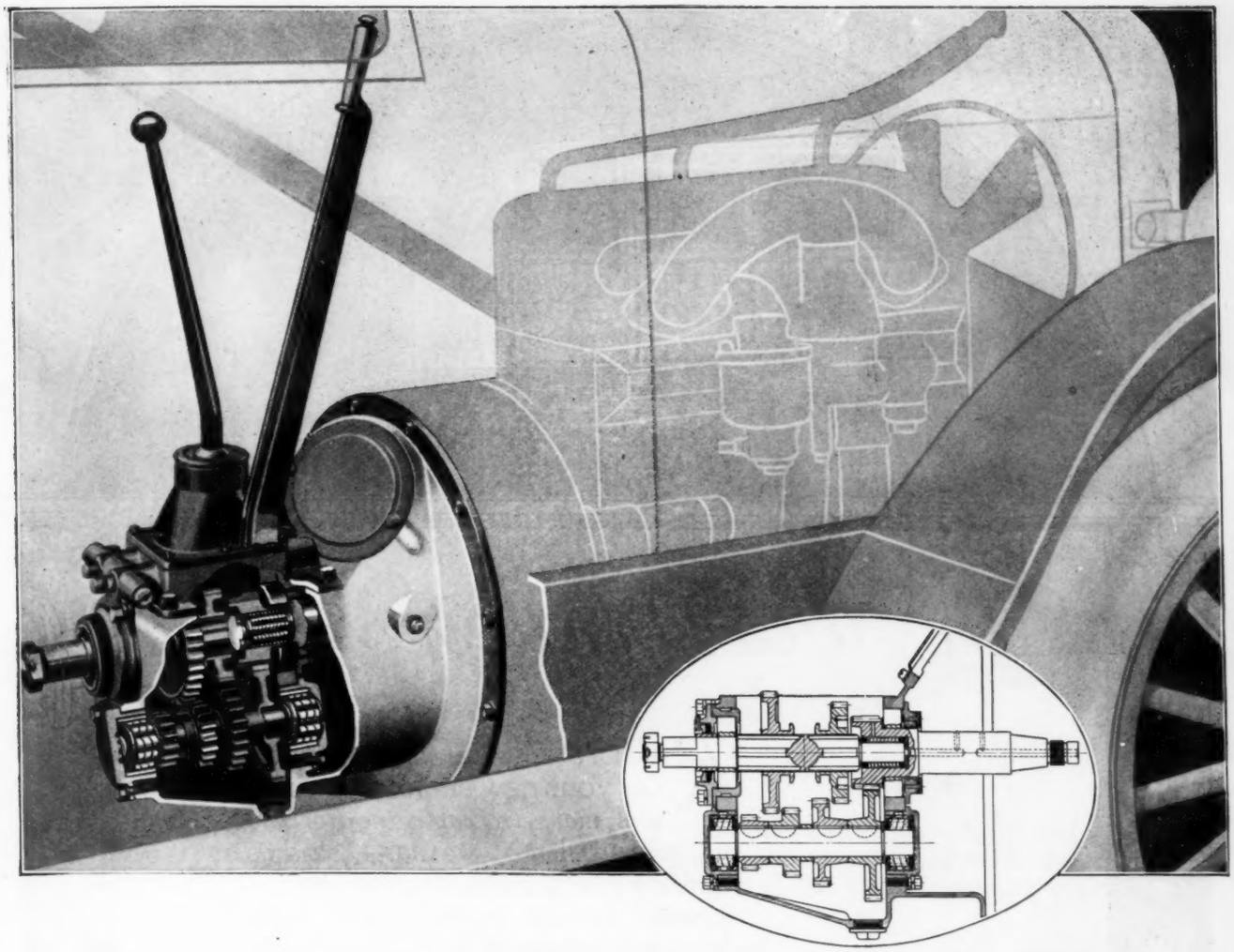
The simple mechanism of the Timken patented Duplex Brake gives the shoes their powerful pressure on the drums. The even distribution of pressure on the full width of the brake drums prevents skewing—no uneven wear.

Timken engineering and manufacturing skill and experience make possible such accurate and sturdy design — such power, ruggedness and reliability—that no demand has ever been made for repair or replacement of Timken Duplex Brake parts.

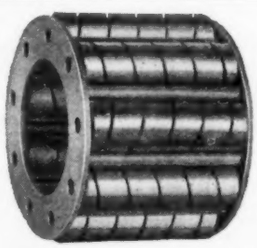
THE TIMKEN-DETROIT AXLE COMPANY · DETROIT, MICHIGAN

TIMKEN AXLES

DTA CO



A Transmission Simplified by Hyatt Roller Bearings



And in Operation

Hyatt Roller Bearings relieve the transmission of all the road shocks and strains—insuring perfect alignment of gears and shafts—thereby minimizing wear and tear.

In addition, they are self-oiling, never need adjustment and survive throughout the life of the vehicle. To have them in your transmission is your assurance of dependable performance.

The compact transmission of this car has Hyatt Roller Bearings on the countershaft ends and on the "spigot" end of the mainshaft, where it pilots into the clutch gear.

The "Spigot" bearing consists of a cage of small rollers. Elimination of races at this point permits holding shaft parts to a minimum diameter. Bearings without inner races are used on the countershaft, thereby doing away with extra parts. End thrust is taken through generous contact surface against plain oil channeled end caps.

This design illustrates the sound manner in which Hyatt Roller Bearings, through their adaptability, simplify construction and enable the manufacturer to build a more satisfactory transmission without adding to the cost of the unit.

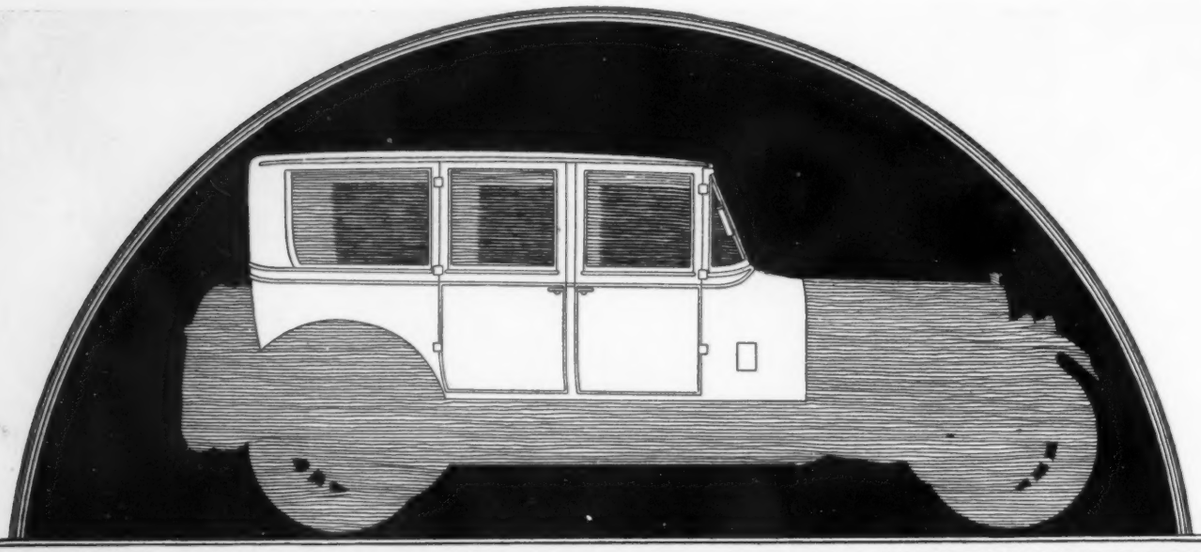
HYATT ROLLER BEARING COMPANY

Motor Bearings Division Detroit, Michigan

Tractor Bearings Division Chicago, Ill.

Industrial Bearings Division New York, N. Y.

HYATT QUIET BEARINGS



An Actual Sales Maker

RAULANG Aluminum Bodies for your new enclosed models *will make traceable sales for you and your dealers.* Raulang Bodies combine every major feature which appeals to car-buyers and puts these sales-making features in *your* cars at a cost to you no greater than you may be paying for inferior coachwork.

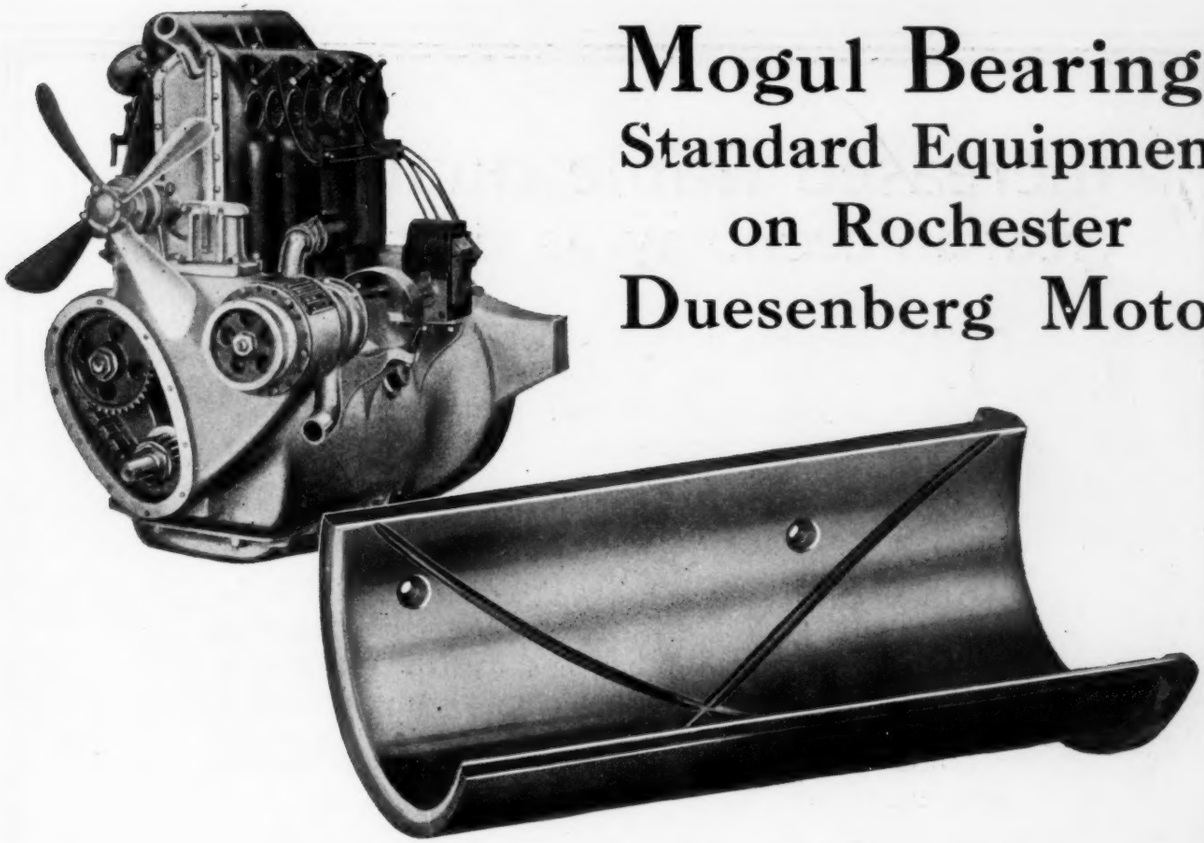
On close competitive sales give your dealers the advantage of the extra attraction of Raulang Bodies.

Raulang Bodies are now available in these models:

REO COUPE
REO SEDAN
LEXINGTON SEDANETTE
RAUCH & LANG BROUGHAM
RAUCH & LANG COACH
STEVENS-DURYEA LIMOUSINE

RAULANG BODY DIVISION
The Baker R & L Co.
CLEVELAND, OHIO. U.S.A.

Raulang
TRADE MARK
AUTOMOBILE BODIES



Mogul Bearings Standard Equipment on Rochester Duesenberg Motor

YOU naturally expect Mogul Bearings on the powerful, sure-working Rochester-Duesenberg motor. The Roamer, the Revere, and the Meteor are powered by this unique and silent engine —which has gained its reputation for dependability through the continuous perfect functioning of every part.

There are definite reasons why Mogul Bearings are standard equipment on the Rochester-Duesenberg and other motors of quality cars. Virgin metals, correct formula, perfect alloys—these, and years of specialized experience in the manufacture of quality bearings are the chief reasons.

And then comes the final reason, the Mogul Trade-Mark—the guarantee of Mogul excellency. Back of it are 14 inspections and a final rigid inspection to detect any imperfection of size, weight, or density. That is why Mogul Bearings meet your specifications to the "one-thousandth part of an inch."

Specify Mogul Bearings

MUZZY-LYON COMPANY DETROIT, MICHIGAN

Mogul

Bearing Alloys *and* Finished Bearings

Increased frame quality is as great an economy as decreased cost

THE new Parish frames of heat-treated Mo-*lyb*-den-um Steel are so much *stronger*, so much *tougher*, so much *lighter* than ordinary steel frames that they represent greater economy in every respect.

For increased quality in an article is as great an expression of economy as decreased cost.

Mo-*lyb*-den-um Steel has been widely adopted in the automotive industry. And we are the first to use it in frame construction. When heat-treated it offers advantages impossible of attainment with any other steel.

Under the extremes of every-day use it develops no permanent "set."

It gives longer life because it has a greater ability to resist shock and fatigue.

It makes possible lighter construction, both in the frame itself and consequently in the other units of the car. This lowers manufacturing costs to you as well as upkeep costs to your customers.

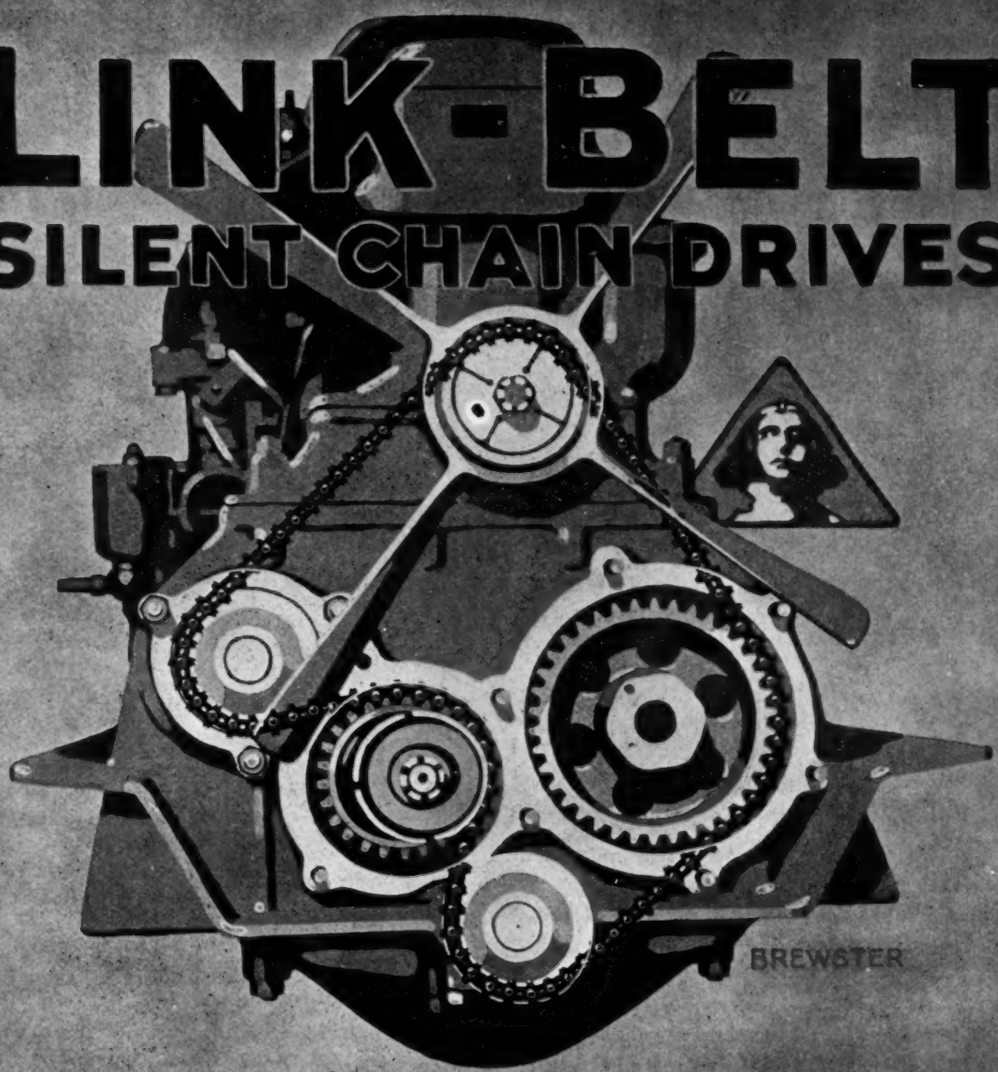
Parish engineers will work with you in designing a Mo-*lyb*-den-um Steel frame for your car, a better method than merely following a specification sheet. Their long experience in the heat treatment of alloy steels *plus* an exhaustive study of Mo-*lyb*-den-um has given them a fund of information freely available.

Write us for particulars

PARISH MANUFACTURING CORPORATION
READING, PA. DETROIT, MICH.

PARISH
MO-LYB-DEN-UM FRAMES

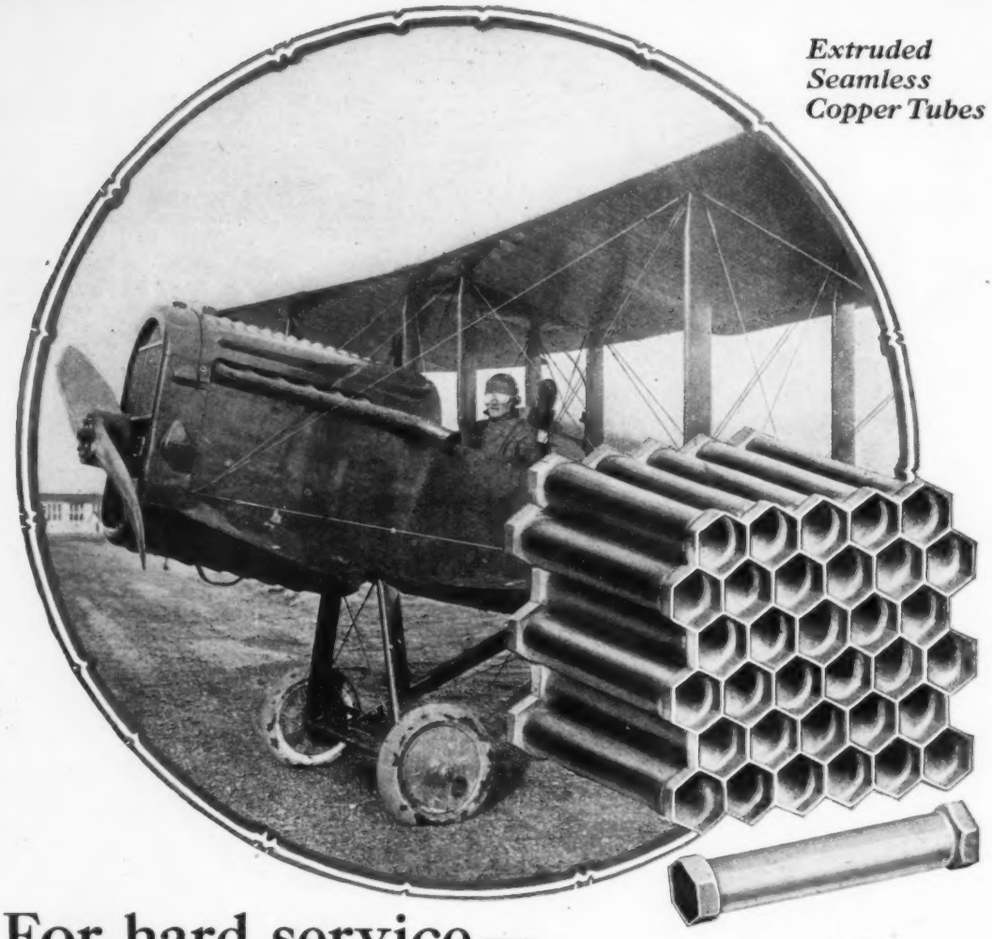
LINK-BELT
SILENT CHAIN DRIVES



FOR MOTOR FRONT ENDS

Link-Belt Silent Chain—a positive yet flexible drive, quiet in its operation, equipped with the Link-Belt tightener that automatically keeps just the right operating tension on the chain at all times.

LINK-BELT COMPANY
INDIANAPOLIS INDIANA



Extruded Seamless Copper Tubes

For hard service— a Cartridge Radiator

It is made of a great many seamless tubes —the picture shows how they are assembled. These tubes can't leak; and they make a radiator that can be guaranteed for the life of a motor car. This is the type of radiator used in all U. S. Army and Postal airplanes.

This construction is adaptable to an almost infinite variety of design; that's why these radiators are so distinctive in appearance. The best European cars have used radiators of this type for many years.

The tubes that go into these radiators are *extruded* from pure copper blanks. They are seamless and uniform. Radiator cores built up from them are strong, rigid, and stay tight. Should an accident damage any of the tubes, they can be replaced easily without taking the radiator down. And these copper tubes are proof against corrosion.

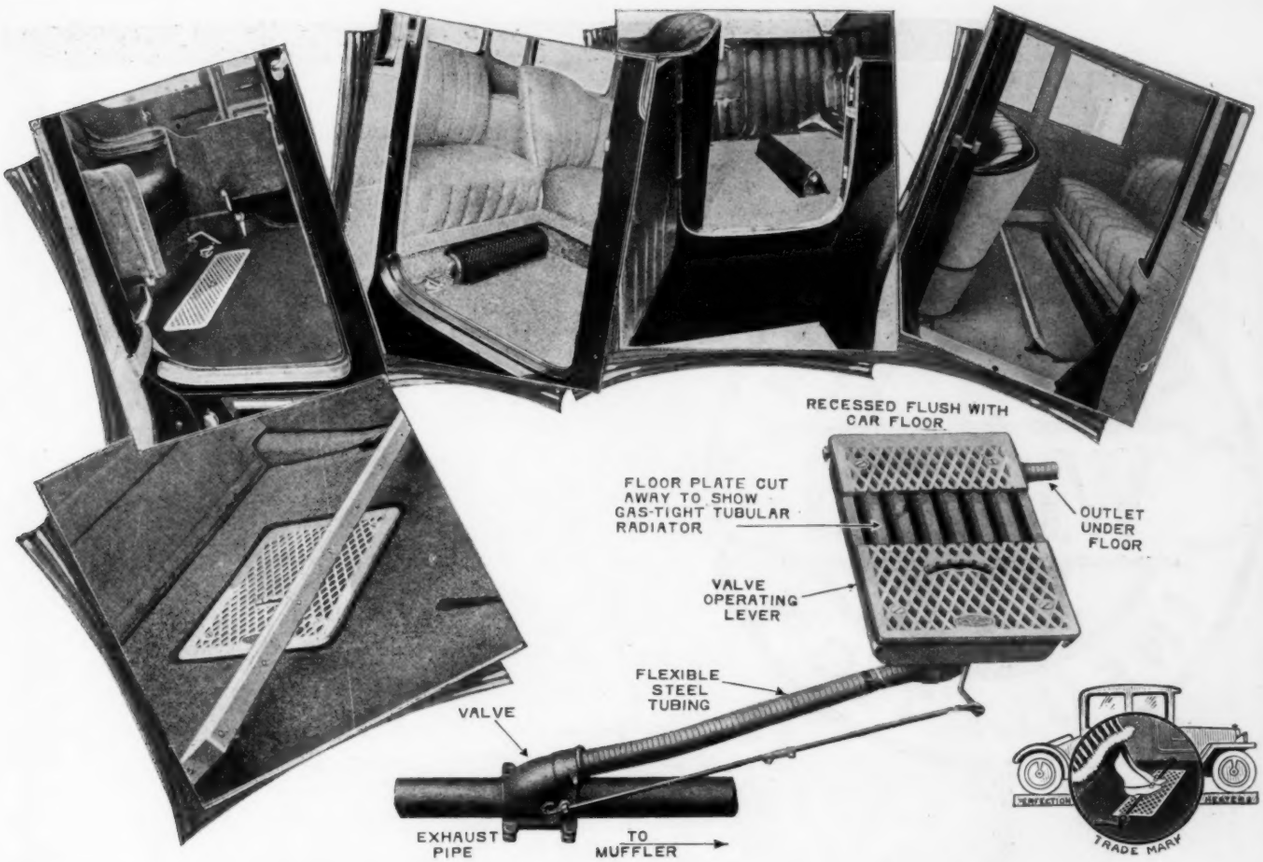
The Ansted Company of New York, makers of radiators for fine cars, use these seamless *extruded* tubes. They think so well of them that they will guarantee radiators made from them for the life of the car.

CARTRIDGE
Seamless Radiator Tubes

Engineers and manufacturers realize the importance of trying every improvement in automotive equipment. This radiator should be an important help in the continual competitive fight against obsolescence. We welcome inquiries; write today.

UNITED STATES CARTRIDGE CO.
Lowell (US) Mass.

SIDE GUIDE & GRIPPER



Some of the cars using Perfection Motor Car Heaters as Standard Equipment on one or more models:

Allen	National
Case	Northway Motors
Cole Aero-Eight	Corp. (truck
Columbia	cab bodies)
Crow-Elkhart	Oakland
Davis	Oldsmobile
Dixie Flyer	Paige
Dorris	Premier (all
DuPont	models)
Gardner	Re Vere
Grant	R & V Knight
Handley-Knight	Scripps-Booth
Haynes	Sheridan
Holmes	Standard Eight
Hudson	Stutz
King	Stephens Salient
Kissel	Six
Liberty	Templar
Maibohm	Velie
Marmon	Willys-Knight
Mercer	Westcott
Mitchell	Yellow Taxicabs
Moon	of Chicago

PERFECTION MOTOR CAR HEATERS

"Heaters go with most closed cars and SHOULD BE STANDARD EQUIPMENT FOR ALL. There seems to be no excuse for putting them out minus a contrivance of this sort."—From Automobile Topics, Feb. 5, 1921.

When we are permitted to announce new contracts recently closed for Perfection Heaters, there will no longer be any doubt that heaters are an essential feature of motor car equipment.

More different makes and a MUCH LARGER TOTAL NUMBER of cars will be equipped with Perfection Heaters by manufacturers this year than ever before.

If you contemplate any price changes the above facts should be carefully considered before revised prices are announced.

"The Heat Is There—Why Not Use It?"

The Perfection Heater & Mfg. Co.

6554 Carnegie Ave. Cleveland, Ohio

SIDE GUIDE & GRIPPER

Willard Advertising and—

Who Pays for It

Willard believes in advertising.

Of course that advertising must be paid for.

By whom?

If it *increases* the price of the battery, your customer pays for it. If it *decreases* the company's dividends the stockholders pay for it. If it *decreases* the dealer's margin of profit he pays for it.

As a matter of fact none of these things happens. What does take place is this: The advertising creates a substantial foundation of good-will that is reflected in a more even demand for Willard Threaded Rubber Batteries. The greater demand permits manufacture on a scale that introduces manufacturing economies and consequently reduces manufacturing costs. The increased production enables us to build up an efficient sales organization and keep it busy, so that still further economies are possible. The result is a lower price to the *consumer* and a better profit for the *dealer*.

Willard Advertising has to be paid for, but it is paid for by economy of material and time that gives added value, and brings added satisfaction to all concerned.

WILLARD STORAGE BATTERY CO.
Cleveland, Ohio

Willard THREADED RUBBER BATTERY

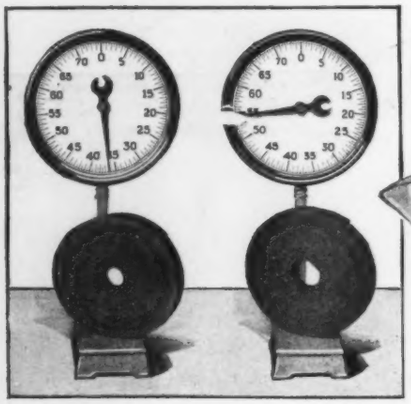
IT is only natural that car manufacturers should advertise the fact that their cars are Bower equipped. The buying public understands the full significance of such a claim.

BOWER
ROLLER BEARING CO.
Detroit Michigan

Exclusive Bower Features

Separate bearing surfaces for load and thrust. Parallel raceways. Self-aligning. Never need adjusting. Does not develop end thrust under loads. Will not bind or end-slip.

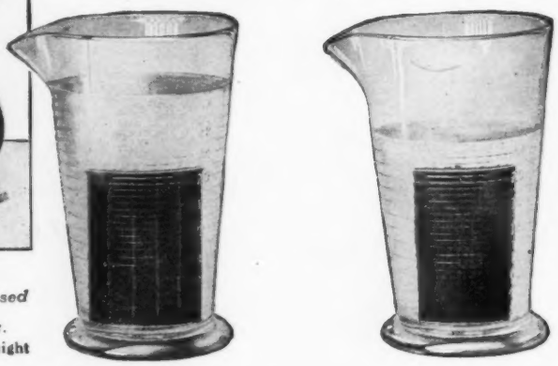
BOWER SAVES POWER



100 ft. ordinary brake lining Weight 36 lbs. 4 oz.

100 ft. Thermoid Hydraulic Compressed Brake Lining Weight 54 lbs. 8 oz.

Thermoid has over *40% more material* by actual weight



Thermoid Hydraulic Compressed Brake Lining, when submerged in boiling water for one hour, absorbs only 8.7% of water — ordinary lining absorbs as much as 23%.

Make these brake lining tests yourself

Know that every foot of lining you install will give satisfactory service

Test No. 1. Cut off, equal length, pieces of brake lining you wish to compare and insert each in a quantity of boiling water. Keep the water simmering for one hour. It will be found that ordinary woven brake lining has absorbed enough water in this time to increase its weight 21% to 23%. Thermoid Hydraulic Compressed Brake Lining will have increased only 8.7%.

This test shows why brakes lined with ordinary lining, affected by moisture, swell and shrink and make constant adjustment necessary. Thermoid is made to resist moisture, oil and gasoline, by the exclusive process of *Grapnalizing*.

Test No. 2. Different makes of brake lining vary greatly in the amount of material per foot. To prove this, weigh a full roll of the same size of each kind. The heavy lining of a given size will wear much more slowly, because it is closer textured and contains more material. It must also wear down more evenly.

In this test Thermoid Hydraulic Compressed Brake Lining shows that by actual weight it contains over *40% more material* than ordinary brake lining.

Install Thermoid with confidence

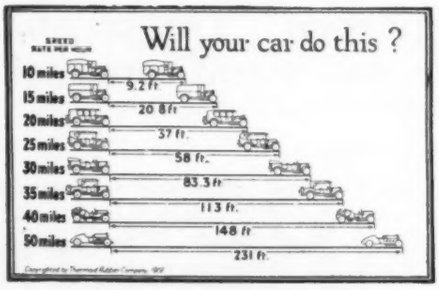
When you install Thermoid Brake Lining you know that it has been proved superior by scientific laboratory tests. It will not grab or slip even when worn down as thin as cardboard.

Because of its unfailing efficiency, the manufacturers of 50 of the leading cars and trucks use Thermoid.

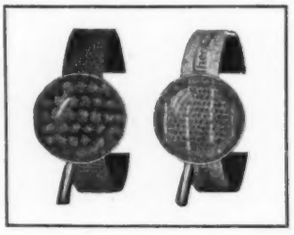
Send for "The Dangers of Faulty Brakes." It contains valuable information which every engineer should know.

THERMOID RUBBER COMPANY
Factory and Main Offices: Trenton, N. J.

New York, Chicago, San Francisco, Cleveland, Atlanta, Detroit, Pittsburgh, Boston, London, Paris, Turin.



Famous Thermoid Standard Chart of stopping distances now approved by Police Officials and Automotive Engineers. Chart shows distance in which car should stop if brakes are efficient. Brakes lined with Thermoid meet these standards.



Ordinary woven lining

Notice the loosely woven texture

Wears down quickly and unevenly

Loses its gripping power as it wears

Thermoid Brake Lining

Hydraulic Compressed.

Notice the compact texture.

Wears down slowly

Gives uniform gripping surface until worn wafer-thin.

Thermoid Brake Lining

Hydraulic Compressed

Makers of "Thermoid Hardy Universal Joints" and "Thermoid Crolide Compound Tires"

Automobile Rear Wheel Hub Flange

Easy Machining of Certified Malleables

In addition to great strength and high ductility, Certified Malleable Castings possess unusually good machining qualities.

Their machinability permits removal of the desired amount of metal in minimum time with minimum tool wear.

High surface speeds of 100 to 150 feet per minute with reasonably deep cuts are possible with Certified Malleables. This means much lower machining costs than with other ferrous metals of comparable shock and strain resisting qualities.

Certified Malleable Castings, the result of years of scientific research, are an important part of automotive construction. They are tough, strong and ductile. They perform their daily work where vibration is most severe, where breakage must be eliminated and where safety is essential.

Members Receiving Certificates for the Quarter Ending March 31st, 1921

Albany Malleable Iron Co.	Albany, N. Y.
Albion Malleable Iron Co.	Albion Mich.
American Malleable Castings Co.	Marion, O.
American Malleables Co.	Lancaster, N. Y. and Owosso, Mich.
Baltimore Malleable Iron & Steel Casting Co.	Baltimore, Md.
Belle City Malleable Iron Co.	Racine, Wis.
Chain-Belt Co.	Milwaukee, Wis.
Chicago Malleable Castings Co.	West Pullman, Chicago, Ill.
Chisholm-Moore Mfg. Co.	Cleveland, O.
Columbus Malleable Iron Co.	Columbus, O.
Danville Malleable Iron Co.	Danville, Ill.
Dayton Malleable Iron Co.	Dayton, O., and Ironton, O.
Devlin Mfg. Co., Thomas	Philadelphia, Pa.
Eastern Malleable Iron Co.—	
Naugatuck Malleable Iron Works	Naugatuck, Conn.
Bridgeport Malleable Iron Works	Bridgeport, Conn.
Troy Malleable Iron Works	Troy, N. Y.
Wilmington Malleable Iron Works	Wilmington, Del.
Vulcan Iron Works	New Britain, Conn.
Erie Malleable Iron Co.	Erie, Pa.
Federal Malleable Co.	West Allis, Wis.
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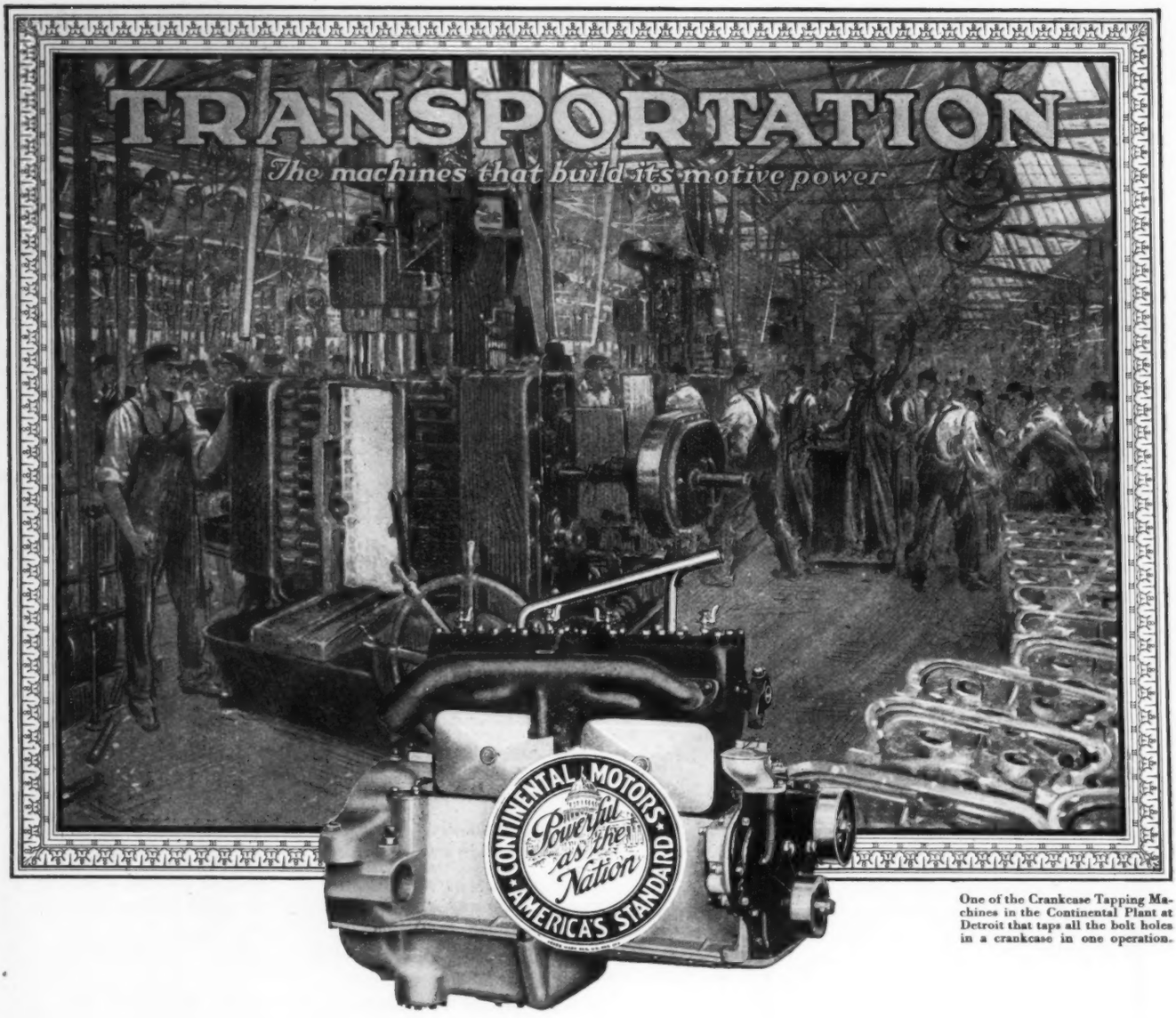
Globe Malleable Iron & Steel Co.	Syracuse, N. Y.
Haskell & Barker Car Co.	Michigan City, Ind.
Illinois Malleable Iron Co.	Chicago, Ill.
Iowa Malleable Iron Co.	Fairfield, Ia.
Kalamazoo Malleable Iron Co.	Kalamazoo, Mich.
Laconia Car Co.	Laconia, N. H.
Lakeside Malleable Castings Co.	Racine, Wis.
Link-Belt Co.	Indianapolis, Ind.
Marion Malleable Iron Works	Marion, Ind.
Moline Malleable Iron Co.	St. Charles, Ill.
National Malleable Castings Co.	Cleveland, O., Chicago, Ill., Indianapolis, Ind., Toledo, O., E. St. Louis, Ill.
Northern Malleable Iron Co.	St. Paul, Minn.
Northwestern Malleable Iron Co.	Milwaukee, Wis.
Pittsburgh Malleable Iron Co.	Pittsburgh, Pa.
Rhode Island Malleable Iron Works	Hillsgrove, R. I.
Rockford Malleable Iron Works	Rockford, Ill.
Ross-Meehan Foundries	Chattanooga, Tenn.
St. Louis Malleable Casting Co.	St. Louis, Mo.
Saginaw Malleable Iron Co.	Saginaw, Mich.
Standard Malleable Castings Co.	Terre Haute, Ind.
Stowell Co.	South Milwaukee, Wis.
T. H. Symington Co.	Rochester, N. Y.
Temple Malleable Iron & Steel Co.	Temple, Pa.
Timken-Detroit Axle Co.	Canton, O.
Trenton Malleable Iron Co.	Trenton, N. J.
Union Malleable Iron Co.	E. Moline, Ill.
Vermilion Malleable Iron Co.	Hoopeston, Ill.
Wanner Malleable Iron Co.	Hammond, Ind.
Wisconsin Malleable Iron Co.	Milwaukee, Wis.
Zanesville Malleable Co.	Zanesville, O.

Certificate holders listed here are manufacturers whose product for the quarter indicated has regularly met the requirements of the Association. In the judgment of the Association's Consulting Engineer, their plant practice is such as to produce uniform material of high character and integrity.

THE AMERICAN MALLEABLE CASTINGS ASSN.
The 1900 Euclid Building Cleveland, Ohio

POSITIVE PHYSICAL AcA CERTIFIED TRADE MARK PROPERTIES

CERTIFIED-MALLEABLE CASTINGS



One of the Crankcase Tapping Machines in the Continental Plant at Detroit that taps all the bolt holes in a crankcase in one operation.

Performance maintained over a long period of years has placed the Red Seal Motor in the niche it holds today in public confidence. What other factor could bring the public to the point where it selects a particular car or truck from the maelstrom of passing traffic and, with an all-sufficient gesture, says "It's equipped with 'The Continental Red Seal?'". ¶ But to the motor vehicle manufacturer, there are other important considerations that prompt the selection of the Red Seal Motor as standard equipment—the unequalled facilities of two of the largest and most completely equipped motor manufacturing plants in the world, the experience of an organization that has concentrated on motor manufacture for years and the bulwark of financial strength that the world knows is behind—The Continental Red Seal.

CONTINENTAL MOTORS CORPORATION

Offices: Detroit, U. S. A. Factories: Detroit and Muskegon

Largest Exclusive Motor Manufacturers in the World

Continental Motors

STANDARD POWER FOR TRUCKS, AUTOMOBILES AND TRACTORS

Two men used to take two minutes to get the 1912 model ready for the road. Today—press a button, snap a switch!

100% Electrified in 1921

Look back with us just ten years.

Recall the automobile with the "honk-honk" horn; with the acetylene tank strapped to the running board; dish-pan headlights with gas burners; dry cell, or perhaps magneto, ignition—while the controversy between "make-and-break" and "jump-spark" still raged. And forget not the crank, the tiresome, wearisome, sometimes dangerous crank!

Look now at your car of today, and see what ten short years have wrought. The horn, the lights, and the starting mechanism are all electrified, each made reliable and economical and safe. All the unwieldiness, the uncertainty, the inconvenience taken out of motoring, and instead, a simplicity and a satisfaction that require but the pressure of a button for their realization. To say nothing of a perfect ignition system thrown in for good measure.

In 1921, for the first time, every manufacturer of passenger automobiles in this country makes at least one model with in-built electrical equipment. Nothing that has happened in the automotive industry speaks more truly of progress than this.

Westinghouse, equipping more makes of cars and trucks electrically than any other manufacturer, contributor from the first to the electrification of the motor-driven vehicle, looks for a time when every truck and every tractor will be similarly modernized.

WESTINGHOUSE ELECTRIC & MANUFACTURING COMPANY
Offices in all Principal Cities · Representatives Everywhere

Always Demand Genuine Parts;
Beware of Pirate Parasites.

Westinghouse

STARTING, LIGHTING & IGNITION EQUIPMENT

Another feature of WOOD WHEEL engineering research that will work for the good of the industry

THE Research Engineering Division of the Automotive Wood Wheel Manufacturers' Association has just issued a comprehensive paper in which the method of storing and caring for Wood Wheels has been reduced to an exact science. This paper will be of immediate interest and value to car and truck makers, service station men and all owners of Wood Wheel equipped vehicles.

Even though Wood Wheels require very little attention and even though car and truck makers regard them as the very criterion of dependability, the Research Engineering Division of the Automotive Wood Wheel Manufacturers' Association spared neither pains nor expense in tracking down their minute characteristics so that methods for obtaining the greatest wheel efficiency at the lowest cost might be definitely formulated.

The findings of this research entitled, "The Care and Storage of Wood Wheels for Trucks," cover every phase of the subject from the time the timber is cut until it has rendered years of service in the wheel itself. It is thorough, semi-technical and complete. A copy will be mailed, post-paid, on your request.

AUTOMOTIVE WOOD WHEEL MANUFACTURERS' ASSOCIATION
105 West Monroe Street Chicago, Illinois

The members of this Association guarantee Wood Wheels of their manufacture for the life of the car or truck on which placed.

The Sign of the Service Station that is equipped for Wood Wheel servicing.

WOOD WHEELS for MOTOR VEHICLES

OVER 50,000 MILES

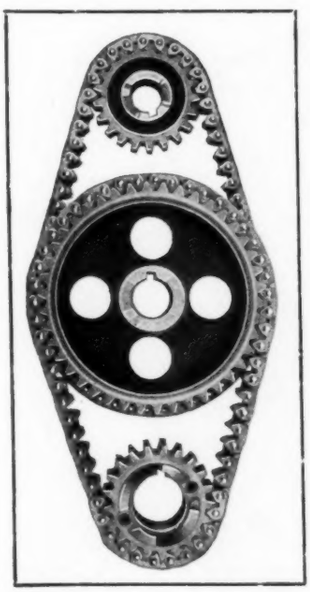
NOW REPORTED ON

"WHITNEY"

HIGH EFFICIENCY

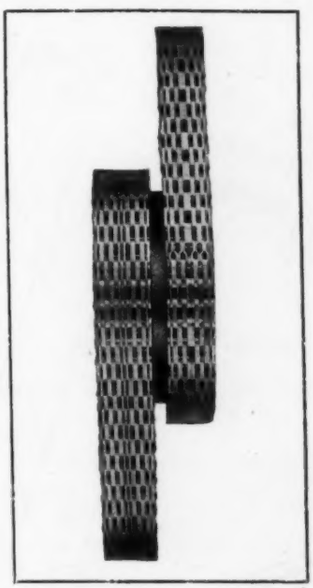
FRONT END MOTOR CHAIN DRIVES

AND STILL IN GOOD CONDITION



Not one of these chains has been known to skip a sprocket tooth

Chains having a high mileage save inconvenience and frequent replacement expense.



THE WHITNEY MFG. CO.

HARTFORD, CONNECTICUT, U. S. A.

RICH TOOL COMPANY

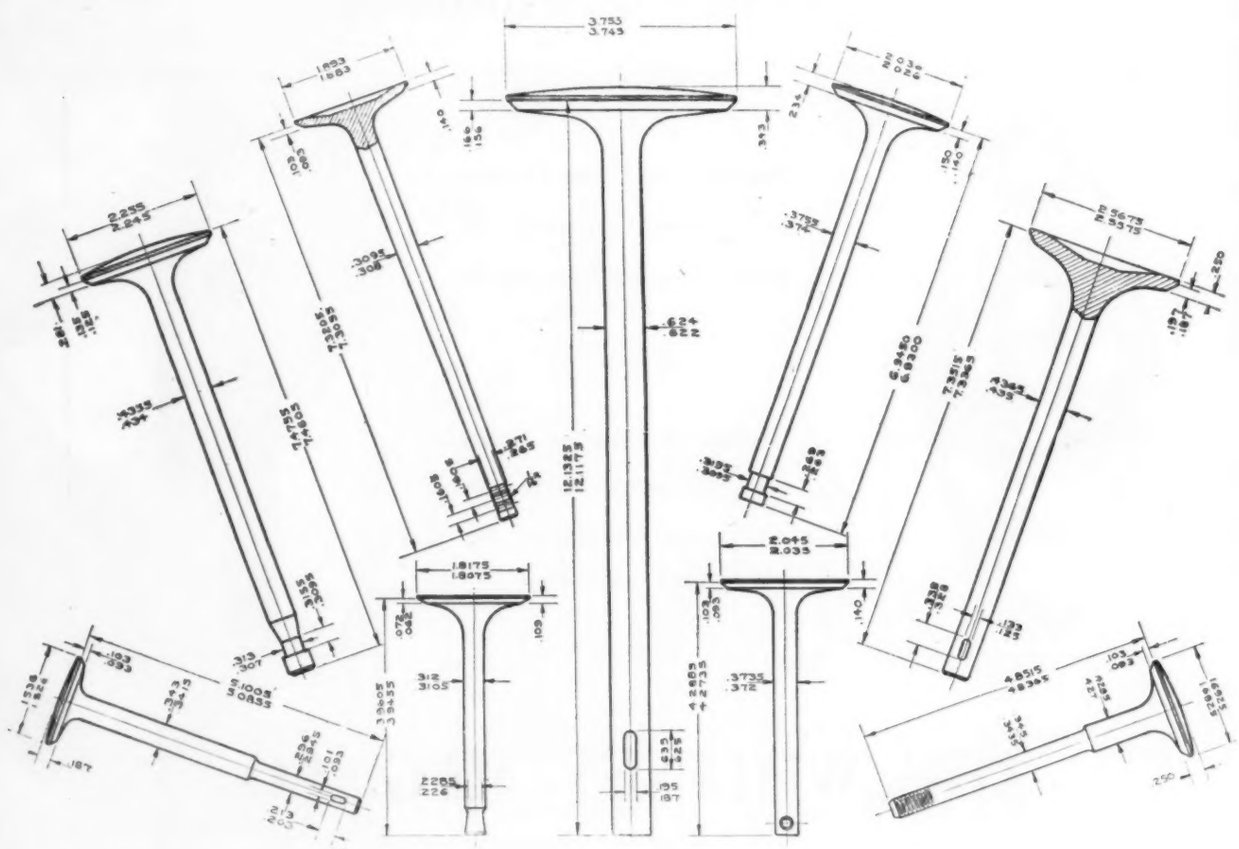
Railway Exchange Bldg., Chicago, Ill. **Kresge Building, Detroit, Mich.**

The cuts below represent valves used in some of the best known present day Aeroplane, Motor Boat and Racing Automobile Engines. They are all products of this Company and most of them have been produced in large quantities and have, therefore, been thoroughly tested in service.

Needless to say, they are all Tungsten Steel, but we also make one-piece forged valves of all other commonly used Alloy Steels, in the manufacture of which we exercise the same care as is used in our Tungsten Valve materials.

One of the newer types of valves which we have been making in very large quantities for the past two years is our Hi-Chromium Valve, which has some very remarkable properties. It is for some purposes an excellent valve and we solicit inquiries from those who are troubled by a persistent burning away of the seats of the valves in their motors.

We also have a material called Cobalt-Crom that possesses the qualities of High-Chromium as relates to resistance to burning, together with a resistance to abrasion or wear and a strength when red hot more nearly comparable to that of High-Tungsten. This material offers excellent promise of good results in engines running for long periods under heavy load without attention, such as marine motors and tractor motors.

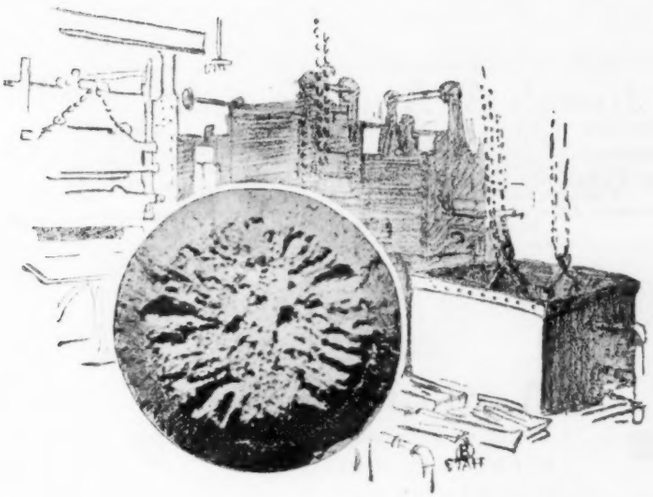


Our Engineering Department is at your service on all questions concerning suitability of material and design.

UMA 2

THE EXACT STEEL OF MANY USES

Responds 100% to Heat Treatment



AGATHON STEEL

Our Uma No. 2 is a perfectly homogeneous and uniform steel and therefore has a wide range of quenching and drawing temperatures.

These properties insure unvarying physical characteristics in the heat treated product.

Would you like to have our metallurgical engineers study your peculiar problem?

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The Elimination of

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Caused by Lack of Balance,
Is the DUTY of Every Auto Manufacturer.

WE SOLVE MA VIBRATION PROBLEMS
Trade Mark Registered

HE knows, and his engineers know, that engine **vibrations,** caused by unbalanced crankshaft or flywheel, create discomfort.

What he may not have known, with certainty, was How to Eliminate that Vibration.

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We say, **"With Certainty,"** because during the past four years of all the MA Balancing Machines that have been placed in use not one has failed to give absolute satisfaction—not one has been returned for any reason.

MA Balancing Machines bear our trademark MA, the initials of Mr. N. W. Akimoff, president of the company.

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PRESSED STEEL FRAMES

FOR

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ALSO

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Cleveland *Fifth City* Ohio, U. S. A.

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There is a standard style of Packard cable for every automotive requirement and for every make of car.

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Warren, Ohio

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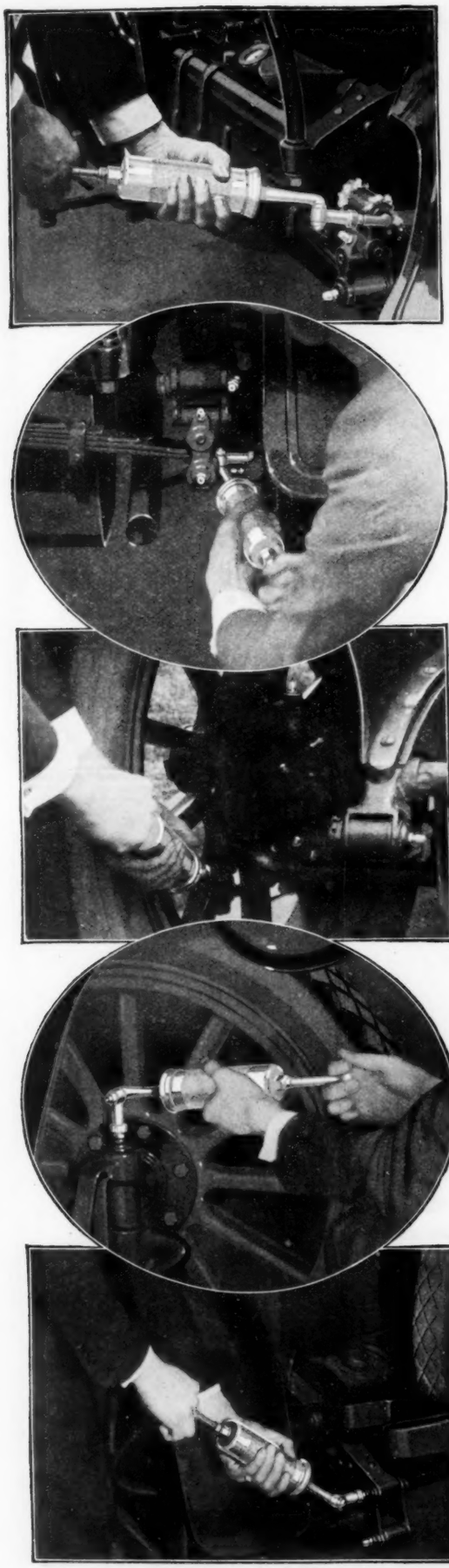

I & M GREESGUN

A *Necessity* on Every Car

If the buyers of your cars are to get full value—if your cars are going to depreciate but slowly—if wear is to be kept down—**GreesGun** equipment is a **necessity,** not merely a desirable feature.

The I & M GreesGun is convenient. Hence it is used frequently and regularly.

It is positive, 500 to 1000 pounds pressure is easily put back of the grease.

It is clean. Check valves in both Gun and nipples make messiness impossible.

It is strong. There is no hose or other easily injured part.

It is quick. Its use is easy; and when it must be refilled, it takes but a few minutes.

We shall be glad to prove all this to you—to send a representative or to send the gun for testing. We know your decision will be that it is a necessity on your cars.

Booklet "Positive Lubrication" will be sent on request. It gives, in detail, the story of this better method of chassis lubrication.

Made and guaranteed by **The Ireland & Matthews Manufacturing Company**

Beard and Chatfield Streets, Detroit, Michigan

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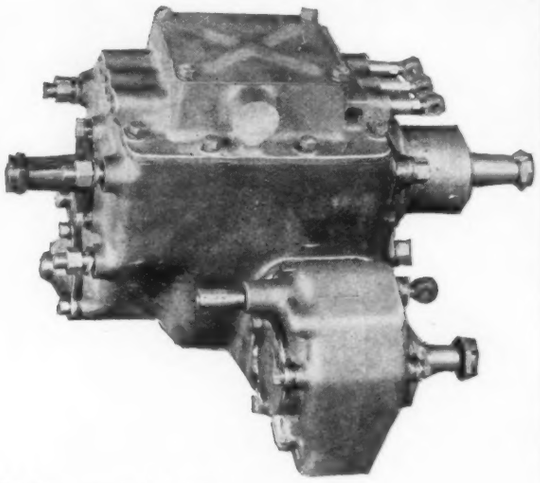
FULLER
TRANSMISSIONS



The use of the Fuller Power Take-off with Fuller Transmissions gives an opportunity for increasing the range of motor trucks considerably. Log loaders, Specially equipped Telephone Co. trucks, Crane equipped trucks, are only fore-runners.

Manufacturers of clutches, controls and transmissions exclusively

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QUALITY Fuller FIRST

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Strom BEARINGS

No Adjustments Required

Once the correct Strom Bearing is selected to carry the required load and has been properly installed, whether it is radial or thrust or a combination of these, the bearing will wear for the life of the car with practically no attention. Automotive engineers appreciate the advantages of a bearing that requires no adjustment. Our experts will help select the right bearing for your installation.

U. S. Ball Bearing Mfg. Co.
(Conrad Patent Licensee)
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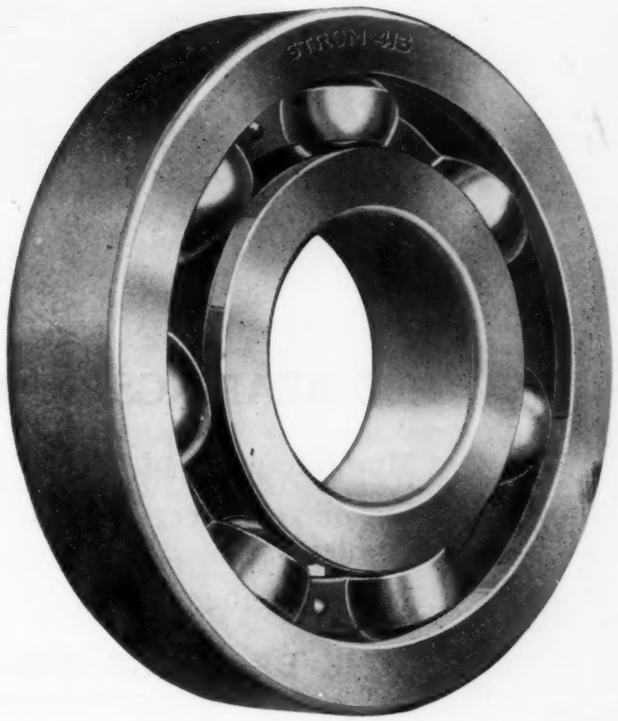

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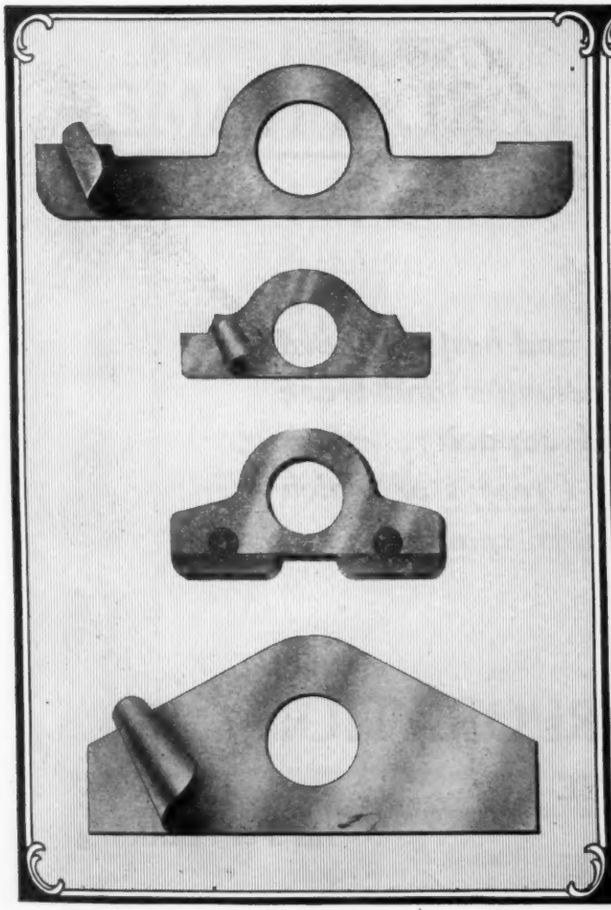

Peel 'Em Down !

Laminated Shims make bearing assembly the simplest of production problems. Adjustment to .002 inch is simply a matter of peeling off the brass layers. After sales upkeep is equally simplified. Our manufacturer customers incorporate Laminated Shims in their own literature as a selling point.

Furnished die cut from sheet Laminum in shapes, thicknesses, and laminations to order. Babbitt-faced to make an all babbitt bearing if desired. Let us figure on your requirements.

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Long Island City, N. Y.

Detroit: Dime Bank Building. St. Louis: Mazura Mfg. Co. Chicago: 1118 S. Michigan Ave.

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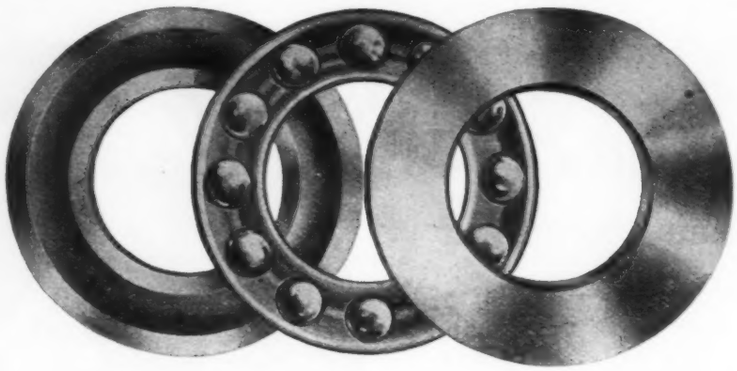

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Let our engineers help to solve your Thrust Bearing problems.

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SMITH PRESSED STEEL FRAMES

We have one of the largest and best equipped plants in the world for passenger and truck frames of any design and capacity. Our facilities for Heat Treated Frames of which we are large producers are unsurpassed.

A. O. SMITH CORPORATION
MILWAUKEE

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GURNEY BALL BEARINGS

Whether in the design of a new machine

or

The operation of one in service
We can effect economies.

Submit us your problems.
Our Engineering Service entails no obligations.

GURNEY BALL BEARING CO., Conrad Patent Licensee **JAMESTOWN, N. Y.**

(1899)

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MILLS GENERAL OFFICES
PITTSBURGH, PA., U. S. A.

COLD FINISHED STEEL PRODUCTS

Free Cutting Screw Stock -- "Columbia" Turned and Polished Shafting -- Axle and Alloy Steel Special Shapes

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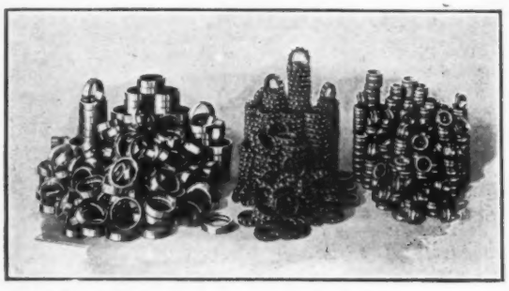
SALES OFFICES: New York Philadelphia Chicago Dayton
SALES REPRESENTATIVES: Atlanta, Ga. Denver, Col. Portland, Ore.
EUROPEAN: Columbia Steel & Engineering Co., Ltd., London, Eng.

INTERCHANGEABILITY

Here is a pile of "NORMA" outer races—
a pile of "NORMA" cages with balls—
and a pile of "NORMA" inner races



You may select any outer race from this pile.

And any cage with balls from this pile.

And any inner race from this pile.

Put them together—and you have a perfect "NORMA" Precision Ball Bearing—accurate as to size and dimensions and alignment—perfect as to true and silent running—as "frictionless" as a ball bearing can be made.

This is "NORMA" interchangeability—and we believe there is nothing to equal it in the world of ball bearings.

Do you know of any other ball bearing that can be assembled from stock this way—and still be a perfect bearing?

Think what this means in facilitating that progressive assembling which reduces costs and increases production.

THE NORMA COMPANY OF AMERICA

Annable Avenue, Long Island City, New York

Ball, Roller, Thrust and Combination Bearings

Positions & Men Available

The following announcements are published for the benefit of members of the Society and the convenience of companies in need of men. No charge whatever is made for this service. In the case of items prefixed by an asterisk further information is withheld at the request of the company or individual making the insertion, but written communications bearing the number of such items will be forwarded by the S. A. E. Office. In other cases further information will be supplied by the Office of the Society. Applications for positions from non-members must be endorsed by a member of the Society.

0024 DESIGNING ENGINEER, with 19 years' experience in designing and developing electrical apparatus, mostly magnetos and kindred apparatus including telephones and switchboards.

0050 GRADUATE ENGINEER with business training desires to make a connection with a progressive organization in a capacity leading to an executive position. Has worked one year as mechanic and two years on production, testing, technical correspondence and sales. Age, 26. Prefer middle west territory.

0051 SPRING MAN A practical engineer who has been ten years in the chassis spring trade and has had an extensive road experience is ready to take charge of design, production, field or experimental work. Can develop the special machinery required to produce efficiently on a large scale.

0052 FACTORY OR PRODUCTION MANAGER, with 12 years' practical experience in automobile and parts manufacturing plants and familiar with costs, production, planning, purchasing and plant engineering, eight years in executive positions, desires to connect with a company where initiative, energy and ability are appreciated. Age 36. Married.

0053 GRADUATE ENGINEER AND METALLURGIST, experienced in axle and chassis design and familiar with modern production methods and heat treating, will be open for new position in 30 to 60 days. Best of references from past and present employers.

0054 AUTOMOTIVE ENGINEER, 33 years of age, with designing experience, possessing good personality and ability to meet people, and now in second year of evening law school, desires to represent or associate with manufacturer's representative in Detroit. Best of references.

0055 INDUSTRIAL EXECUTIVE with eight years' experience in the operation of modern factories producing pressed, rolled and welded parts. Also experienced in selling, maintenance, development and design of machines. Possesses a knowledge of accounting and production control.

0056 MECHANICAL DRAFTSMAN Technically educated and experienced on passenger car and truck detailing and layout work, lately engaged in the layout and design of passenger-car and truck axles, desires a position with motor-car builder at Detroit or Cleveland.

(*Continued on page* 52)

New Process Gears

Cut steel gears—Spurs, Straight Bevels and Spiral Bevels—for transmissions and drives, also complete Differentials

***for* Automobiles Trucks and Tractors**

correctly and economically made by 10 acres of latest type machinery.
Our engineers are ready to confer with you.

Quality—Quantity—Quickness

Member of the

New Process Gear Corporation
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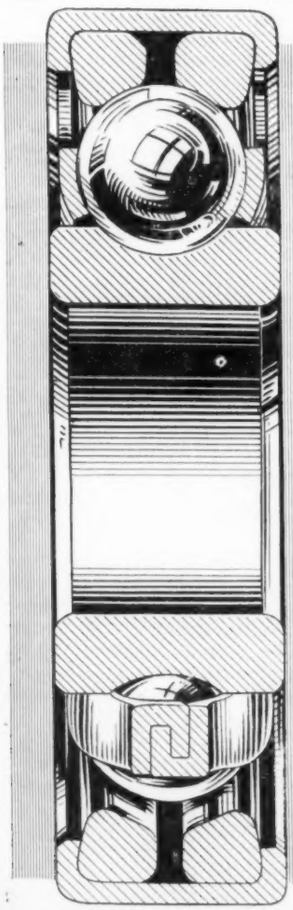

Alignment

The permanent, accurate alignment of the Schatz Universal goes far to eliminate friction and adds greatly to the life of the machine, as well as of the bearing itself.

The Federal Bearings Co., Inc.
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Great Britain: 37 Sheen Road, Richmond, London

Schatz
UNIVERSAL
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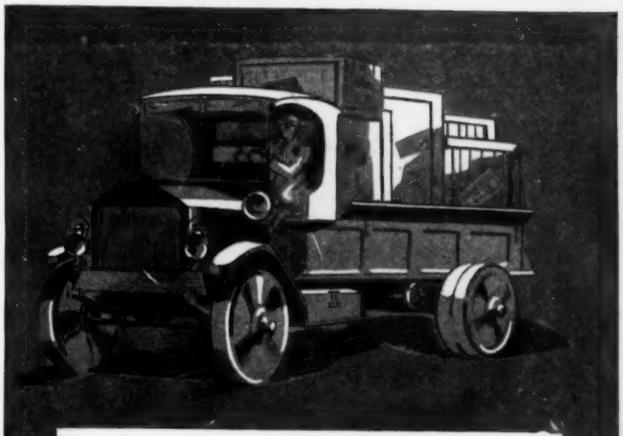
BALL BEARING



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Machines as readily as lead

VUL-COT Fibre comes in sheets, rods and tubes. It's dense and tough and has an extremely low friction co-efficient. This gives it the greatest wear resistance of any insulator.

VUL-COT Fibre is always uniform—never contains fissures, hard or soft spots, grit or other foreign matter. Edge tools used in machining it are subjected to little wear. Here are the physical properties of *VUL-COT* Fibre:

Tensile strength 9,000 to 14,000 pounds per square inch—compressive strength 32,000 to 67,000 pounds per square inch—resistance to shearing 9,000 to 13,000 pounds per square inch—specific gravity 1.2 to 1.5. Electrical rupture 100 to 400 volts per mil.

—And these are the properties that have made *VUL-COT* Fibre "The Material with a Million Uses." We have a book bearing this title. We'll send it: Tell us where. Also consult the *VUL-COT* Service Dept. in your individual problems.

BY INVITATION MEMBER OF

AMERICAN VULCANIZED FIBRE CO.
521 Equitable Bldg., Wilmington, Del.

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Complete Stock for Immediate Shipment at Chicago
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Canadian Agents *Northern Electric Company* LIMITED
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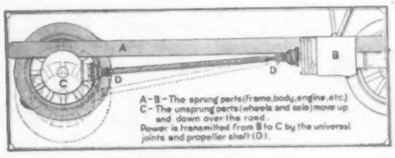
SPICER equipped vehicles are in high favor with two great classes of experienced motorists: those who are so situated financially that they buy the best from force of habit, and those whose means require them to buy the best for reasons of economy.

Write on your business letterhead for booklet concerning Spicer Universal Joints and Propeller Shafts.


A
B
C
D
D
A-B-The sprung parts (frame, body, engine, etc.)
C-The unsprung parts (wheels and axle) move up and down over the road.
Power is transmitted from B to C by the universal joints and propeller shaft (D).

SPICER MANUFACTURING CORPORATION—SOUTH PLAINFIELD, N.J.

Spicer

UNIVERSAL JOINTS AND PROPELLER SHAFTS

MEN AVAILABLE
Continued

0057 PRODUCTION MANAGER AND ENGINEER with 15 years' experience in the building of passenger cars and trucks, desires a position of a similar nature or as assistant to the general or works manager. At present production manager of a large automobile firm.

0059 MECHANICAL, AUTOMOTIVE OR SALES ENGINEER. Technical graduate of executive ability and broad experience and capable of taking entire charge of engineering and experimental departments of large truck, tractor or engine firm, wishes to become associated with an organization where past experience can be utilized. Fifteen years' technical and practical experience on automotive engines, automobiles, trucks, tractors, special machinery, tools, etc., both in engineering and production departments.

0060 SERVICE MANAGER with 18 years' experience in factory and large service stations on passenger and commercial cars. Personal interview desired.

0062 EXECUTIVE wishes to join a live business organization. Experienced in engineering and production departments, purchasing and general plant supervision in shops employing 200 men.

0063 PRODUCTION ENGINEER OR SHOP SUPERINTENDENT wishes a position with an automobile or truck builder. Over 15 years' practical experience. Prefer Detroit or vicinity, but would consider other locality.

0064 ENGINEER capable of designing and putting in production a line of trucks or tractors. Position as chief engineer or chief draftsman with new truck or tractor company is desired.

0066 ENGINEER Technical graduate with 11 years' practical experience, 5 years in truck design and construction. Has held positions as truck designer, chief draftsman and chief engineer. Capable of organizing and systematizing an engineering or production department so as to produce maximum results with minimum labor and expense. Open for an executive position with a responsible truck company.

0067 ENGINEER Desires position with progressive company to take charge of engineering, designing, experimental and research work and assist sales and advertising departments in preparation of useful reliable data. A broad-minded college graduate and designer of successful engines. Experienced on all parts of automobile and truck chassis design and dynamometer tests.

0068 MECHANICAL DESIGNER with 10 years' general design work and five years gasoline engine design experience at present occupying position of assistant general superintendent wishes a position with firm building power farm machinery or doing truck work. Design or production department preferred.

0070 AUTOMOTIVE ENGINEER with 15 years' experience in the design, construction, testing and production of automobiles, trucks and their component parts. Energetic with executive ability and originality. At present engineer for large Eastern manufacturer of lighting, starting and ignition equipment. Would consider position as engineer or sales engineer with progressive organization.

0071 ENGINEER Executive with 12 years' automobile experience as designer, engineer, chief inspector and assembly superintendent and capable of organizing and managing these departments. Familiar with principles

(*Continued on page* 54)

Johns-Manville Automotive Equipment

Non-Burn Asbestos Brake Band Lining.
Johns-Manville Brake Lining for Ford Cars.
Johns-Manville Clutch Rings and Facings.
Johns-Manville Speedometers.
Johns-Manville Speedometers for Ford Cars.
The Jones Recorder for Commercial Vehicles.
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Johns-Manville Hub Odometer for Ford Commercial Vehicles.
Johns-Manville Auto Tape.
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"Noark" Auto Lighting Fuses and Clips.

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Incorporated
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Shop or Power Plant, Aeroplane, Automobile, Truck Tractor or Motor Boat

Our magazine LUBRICATION is a part of Texaco Service. It is devoted to Lubricants and their application, exclusively, and sent Free to all interested in the subject.

You can get a copy each month by asking us to put your name on our mailing list.

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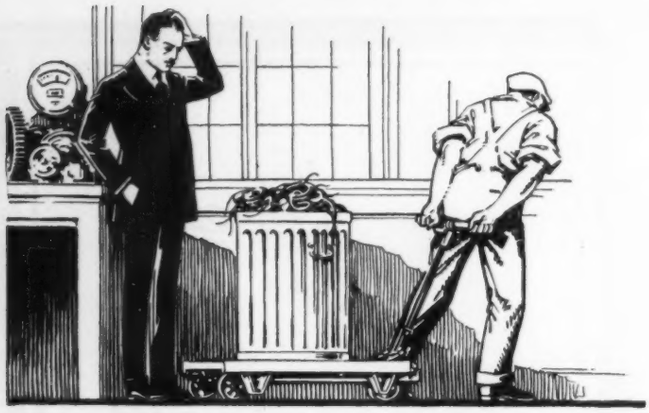
Silvertowns hold their leading position today because back of them is the fifty years of experience in rubber manufacturing which imparts tangible betterness to every product bearing the Goodrich name. The handsome appearance of Silvertowns is an outward indication of the unusual strength and durability built into them

Goodrich Silvertown CORD TIRES

BEST IN THE LONG RUN
FOUNDED IN 1870
TRADE MARK



You can't sell rejected windings

Suppose you are winding field coils or armatures, you can't sell the spoiled ones, can you? And the more there are that fail to pass inspection, the higher your production costs, of course.

Therefore, in buying your magnet wire, you naturally seek not the lowest price, but the lowest cost; quality expressed not in terms of dollars and cents, but in winding efficiency.

Acme Magnet Wire has in many instances reduced winding costs from 10% to 20%, for the simple reason that it has enabled the operators to make more windings—and more good windings that will pass inspection—than wire that is not made so carefully to meet *actual winding requirements*.

Our own experience in coil winding on a large scale has taught us how to make magnet wire that *"goes in the space."*

That means wire that is uniform in diameter, smooth, free from bare spots; wire that has no lumps in it, and that always ends up with the right number of turns in the finished coil of specified dimension. Operators like Acme Wire; it comes off the spools without kinking or snarling. Acme Wire saves them trouble and enables them to earn more money.

The Acme Wire Co. has pioneered in the development of silk- and cotton-covered enameled wire—being the first to successfully market this type of insulation. The Acme experience in this particular field has been such that frequently Acme can make recommendations for the use of cotton- or silk-covered enameled wire instead of the heavier all-fabric wire, in a way that saves the user a considerable amount—and at the same time improves the job.

Illustrated Catalog on request to Engineers and Purchasing Agents

THE ACME WIRE CO., New Haven, Conn.
NEW YORK CLEVELAND CHICAGO

Acme Wire

"It goes in the space"

MEN AVAILABLE
Continued

of factory organization. Excellent references. Detroit preferred.

0072 ENGINEER Technical graduate. Twelve years' experience in internal-combustion engines including aviation engines. Capable of taking charge of assembly, experimental, production, testing, designing and layout work. Desires to make connection with a reliable and progressive corporation.

0073 MECHANICAL DRAFTSMAN Experienced in motor-truck layout work and checking; also shop experience. Technical graduate. Newark, New York City or vicinity preferred.

0074 AUTOMOTIVE ENGINEER Technical graduate experienced in chassis design and layout, axles, gas engines, research and experimental work. Familiar with general body layout in proper relation to chassis. Age 25. Married.

0075 ENGINEER, an accepted authority on automotive design and development work with 20 years' practical experience will give his services for a few months to assist manufacturers in the solution of their problems.

0076 SALES ENGINEER with headquarters at Detroit desires to represent manufacturers of wood and metal patterns, gages, jigs and fixtures, forgings, stampings, grey iron and malleable castings, production tools and screw-machine products. Territory covered Michigan, Illinois, Indiana, Ohio, Pennsylvania and New York.

0077 RESEARCH ENGINEER, capable of scientific investigation or development of unperfected devices. Competent on any mechanical problem; inventive; with wide designing experience supplemented by the authorship of technical articles and teaching. Specialty internal-combustion engines. Age 36, married.

0078 CHIEF ENGINEER OR ASSISTANT Graduate mechanical engineer, age 27, with six years' experience in the design, development and application of various types of automotive engine, desires to return to passenger-car field. At present holds responsible engineering position with engine builder and wishes a similar place with a progressive automobile company. Available on reasonable notice.

0079 WORKS MANAGER, having broad experience in the management of plants employing from 500 to 3000 men for last 16 years is available for immediate engagement. Experience includes automobile parts of various kinds, steam turbines and powerplant auxiliaries. Practical man and good organizer. Age 38.

0080 DESIGNING ENGINEER AND FACTORY MANAGER with 13 years' experience in the automotive industry in production and tool engineering and factory management and good technical and practical training. An American, 33 years old. At present chief engineer and assistant factory manager. Has held responsible positions with well-known companies in the industry. Would like a position with a progressive company.

0081 MECHANICAL ENGINEER with 12 years' experience in the design and manufacture of automotive equipment, capable of taking full charge of the designing of tools, dies, jigs and fixtures and factory equipment for quantity production of steel bodies for trucks and pleasure cars.

(*Continued on page* 56)

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SCHRADER UNIVERSAL TIRE PRESSURE GAUGES.

You will get *your* share of these sales and profits if you keep your stock adequate to meet the demands for

SCHRADER UNIVERSAL TIRE PRESSURE GAUGES. PUMP CONNECTIONS. KWIK-ON-AN-OFF DUST CAPS. VALVE REPAIR TOOLS, etc.

When placing your next order be sure to include SCHRADER UNIVERSAL "AIR CHUCKS", for service air lines. The only Air Chuck on the market which *cannot* injure the Valve Inside.

Your Jobber carries our complete line.

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INTEGRAL CAM SHAFTS

Built By
MUSKEGON MOTOR SPECIALTIES COMPANY
MUSKEGON, MICHIGAN.

By Reputation —"The Best Cam Shafts Made"

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AFTER nearly half a century of consistent effort to make only the best, we've an old-fashioned craftsman's pride in the superior drop-forgings that bear Williams' trade mark, ⟨W⟩. You'll never find it on inferior work.

No matter what the purpose, if dependable drop-forgings are needed, whether simple or complicated, large or small, we are prepared to make them. Correspondence invited.

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often cheaper than castings
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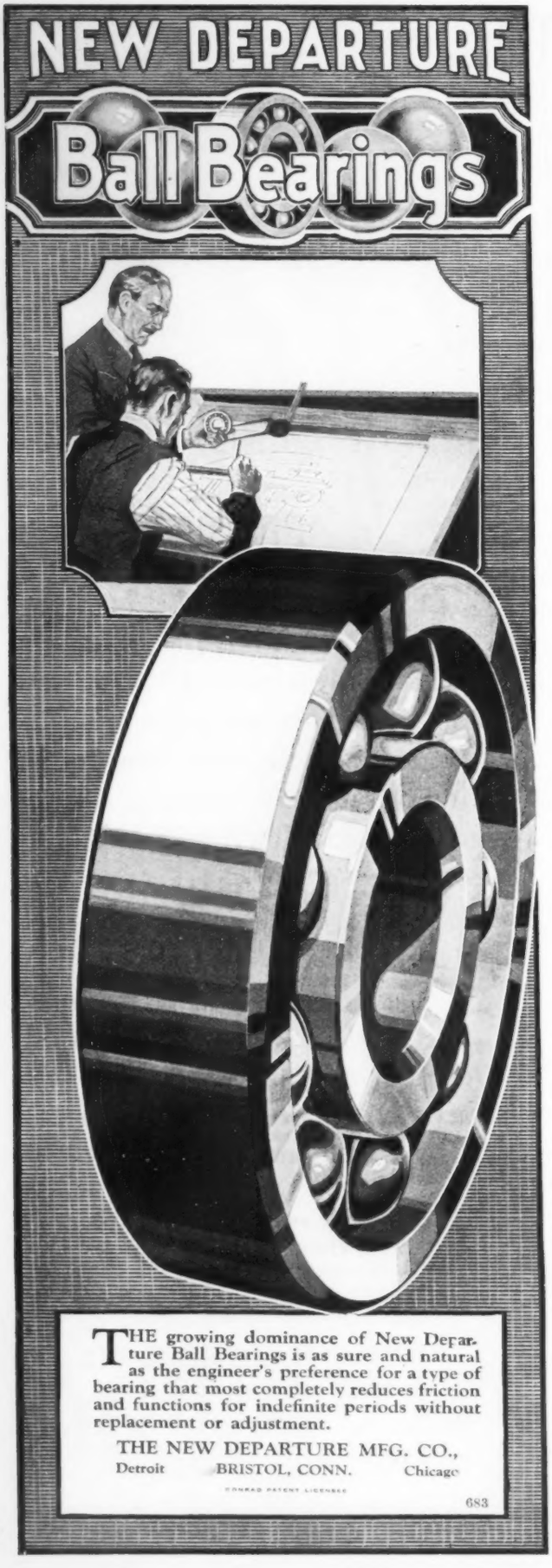

NEW DEPARTURE
Ball Bearings
THE growing dominance of New Departure Ball Bearings is as sure and natural as the engineer's preference for a type of bearing that most completely reduces friction and functions for indefinite periods without replacement or adjustment.
THE NEW DEPARTURE MFG. CO.,
Detroit BRISTOL, CONN. Chicago
683

MEN AVAILABLE
Continued

0082 DESIGNING DRAFTSMAN would like opportunity to branch into the selling field. Has had 2 years' automobile and 8 years' mechanical experience. Willing to go anywhere. Age 29.

0083 ENGINEERING EXECUTIVE. University graduate with 9 years' experience in design, factory layout work and plant engineering, laboratory and experimental work and general factory inspection, desires to make new connection with broader opportunities. Thoroughly experienced in industrial organization and production methods. Several years' experience in sales engineering and service.

0084 EXECUTIVE DEVELOPMENT ENGINEER. Graduate mechanical engineer with textile engineering experience. Last 10 years with a large progressive tire company. Is thoroughly familiar with tire design, production and sales methods, has initiative and is capable of organizing and getting results.

0085 GRADUATE MECHANICAL ENGINEER. Ten years in rubber tire manufacturing including 3 years as factory representative abroad. Also had extensive airship engineering and testing experience during the war and is not restricted to the rubber business. Sales engineering or financial lines preferred. Age 32; unmarried. Will go anywhere in the United States.

0086 ENGINEER with 10 years' experience in the design and development of automotive equipment including gasoline and electric trucks and tractors. Prefers to locate in the east. Age 31. Available July 1.

0087 DESIGNER wishes a position with a progressive company. Experienced in the complete design of automobiles and trucks and has had 14 years' experience in the development of automobiles, airplanes and marine engines.

0088 DESIGNING ENGINEER. Progressive and thoroughly competent to take charge of design and development work. Has spent 8 years in the motorcycle industry and is well acquainted with automobile design. Available on short notice.

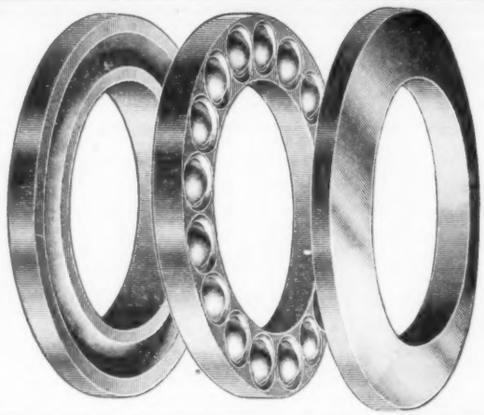
0096 AUTOMOTIVE ENGINEER desires a position as chief engineer or assistant with commercial or passenger car company. For the past 2 years has been chief engineer with a truck building company with full charge of all design, inspection and experimental work. Location preferred, Illinois or Indiana.

0097 MECHANICAL ELECTRICAL ENGINEER Technical and practical executive with 20 years' experience in designing, shop supervision and materials. Has ability to produce from designing through experimental and manufacturing stages. For past 5 years with a large manufacturer in the lighting and magneto field. Capable of holding a position as chief engineer.

0098 MECHANICAL DRAFTSMAN with technical education and six years' experience, desires a position in New York City or vicinity. Experienced in the design and detailing of passenger cars and motor trucks. Age 23. Married.

0099 BODY OR ASSISTANT CHIEF ENGINEER with European education and training and eight years' practical experience in complete car design; chassis and body, specializing in body engineering, including supplementary body and sheet metal parts and all depart-

(*Continued on page* 58)



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All cars look good when they're new. It's what the owners think of them the second season that counts.

All bronze-backed babbitted bearings look alike when they're new. The eye can't distinguish the real qualities. Ringing for bond is necessary as a general test, but it tells no more about the wearing qualities than running a new car around the block. It's a mighty poor bearing that isn't completely bonded before it goes into the motor. What interests you is how long it will stay that way.

There are plenty of bearings which ring as clear as American Bearings when they're new. That's why we want you to make a real test for bond strength. Flatten a few. On ordinary bearings the babbitt will peel away like a banana-skin. On American Bearings it clings as tightly as ever. Even a microscope reveals no laxity. That's the kind of bearing for *your* motor.

The extraordinary bond strength of American Bearings is due to the patented Centrifugal Force Process. They are made to your specifications of virgin metal, and the same strength of bond is guaranteed regardless of what your analysis may be.

CENTRIFUGAL FORCE PROCESS American Bearings

There are other interesting points of advantage for American Bearings. Ask us about non-porous and non-crystalline structure, for instance.

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Indianapolis, Ind., U. S. A.

AMERICAN BEARINGS

MEN AVAILABLE
Continued

ments concerned. Able to assume charge of body designing, engineering and experimental division of an automobile or body plant. At present holds a similar responsible position with company building high-grade cars. Best of references can be furnished.

0100 CHIEF DRAFTSMAN with firm of consulting and automotive engineers, who has had 10 years' experience in passenger-car, truck and tractor design and production; will consider a position as engineer or assistant engineer with well-established firm in the Middle West. Age 30. Married.

0101 MECHANICAL ENGINEER Technical graduate; 33 years old, married, with 12 years' experience in designing and building automobiles, including racing cars. Has developed and built a high grade four cylinder light car and is at present employed as chief engineer of an automobile company.

0102 MECHANICAL ENGINEER with 18 years' experience desires to get in touch with progressive automobile builder who is in need of a man familiar with quantity production. St. Louis preferred.

0103 ENGINEER AND EXECUTIVE Practical man with 12 years' experience in the construction of commercial and passenger vehicles and gasoline engines and an authority on internal-combustion engines who can organize and direct. Is now connected with large automotive corporation as assistant engineer and superintendent, but desires a position with a greater future. Would serve as assistant. No preferable location. Good references. Available on reasonable notice.

0104 SALES ENGINEER wishes to represent manufacturer of automotive parts in the Rocky Mountain territory and on the Pacific coast. Has had 15 years' experience in sales, service, engineering and production in automotive and allied lines. Now located in Oregon. Age 36. Married.

0105 ENGINEER Technical man with 10 years' experience in design, experimental work and production of various grades of passenger cars is open for a position with a progressive firm as an executive or assistant. Willing to represent parts manufacturer as sales engineer. Good references.

0106 METALLURGICAL ENGINEER desires new connection as director of research department. Has had extensive experience in heat-treating, foundry and steel mill practice and is also familiar with shop problems and cost accounting and production systems. Qualified to fill an executive position. Can furnish the best of references.

0107 EXECUTIVE with 11 years' experience as an executive and engineer in automobile and aviation engine plants, a thorough technical education and broad experience. Possesses the ability to organize and handle men and is progressive and confident. An excellent correspondent, clear thinker and hard worker. Eastern location preferred. Available in July.

0108 ELECTRICAL AND MECHANICAL ENGINEER Experienced in testing, automotive design, inspection, sales and research work for six years. Is qualified to act as assistant sales manager, assistant chief engineer o.

(*Continued on page* 60)

Pattern Equipment Designed—Not Just MADE

Have YOU Ever Tried

A "STAND PAT" QUANTITY PRODUCTION EQUIPMENT DESIGNED
BY STANDARD PATTERN WORKS' ENGINEERS
and furnished complete—even to the special flasks required?

UP-TO-DATE PATTERN EQUIPMENT is the one sure way to cut costs and insure production.

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7% lighter in weight.

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AMERICAN MANGANESE BRONZE CO.
Holmesburg, Philadelphia, Pa.

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CLEVELAND
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1646 Woodward Ave.

PITTSBURGH
316 House Building

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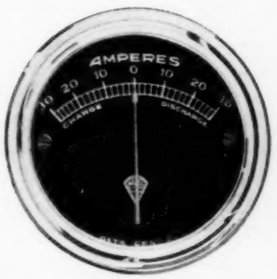
285 Beaver Hall Hill

Watch Your NAGEL AMMETER

The dependability and the accuracy of an ammeter is the true measure of its value. That the Nagel is standard equipment on more than two millions of cars is good evidence of its high quality and dependability.



THE W.G. NAGEL ELECTRIC CO.
TOLEDO, OHIO.

The Nagel Ammeter is standard equipment on Austin, Auburn, Anderson, American, Beggs, Bell, Briscoe, Bour Davis, Chevrolet, Curtis, Collier, Handley-Knight, Haynes, Luverne, Maxwell, Mitchell, Moore, Oakland, Oldsmobile, Jackson, Overland, Pan, Peugeot, Piedmont, Security, Stanwood, Stephens, Studebaker, The Southern Six, Vogue and Willys-Knight passenger cars, and Atlas, Collier, Commerce, Denby, Gramm-Bernstein, Garford, G. M. C., Kerns Dughie, Nash, Nelson, Olds, Republic, and Stewart motor trucks. Also endorsed by use by the makers of the Auto-Lite, Bijur, C. A. Vandervell (London, Eng.) and Remy Starting and Lighting Systems.

EA MOTOR DRIVEN WARNING SIGNALS

Especially Adapted for Equipment Purposes

E·A·LABORATORIES, Inc.
BROOKLYN, N.Y., U.S.A.

To the Engineer:

By specifying "Bound Brook" (graphite-and-bronze) or "Nigrum" (impregnated hardwood) Oil-less Bushings for chassis bearings, and other units in automotive apparatus, you protect your design against the deteriorating effects of neglect. When a careless or forgetful owner fails to lubricate the chassis bushings according to your instructions, "Bound Brook" and "Nigrum" Bushings will act to check the rapid wear that would otherwise result. The Bound Brook Catalogue contains matter of technical interest to automotive engineers. A copy on request.

All Genuine Graphited Oil-less Bushings have always been made at Bound Brook, U. S. A.

BOUND BROOK OIL-LESS BEARING COMPANY

Specialists in the manufacture of Oil-less Bushings for more than a third of a Century

BOUND BROOK NEW JERSEY

Detroit Office: 1723 Ford Building

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OIL-LESS BUSHINGS
Graphite & Bronze
TRADE MARK REG. U. S. PAT. OFF.

NIGRUM
IMPREGNATED HARDWOOD
OIL-LESS BUSHINGS
TRADE MARK REG. U.S. PAT. OFF.

MEN AVAILABLE
Concluded

director of purchasing. East preferred but not essential. Age 27. Married.

0109 EXECUTIVE with eight years' experience in the production, assembly, testing and repairing of automobiles and automobile and aeroplane engines. Location, New York or New Jersey preferred.

0110 YOUNG MAN wishes to connect with a company building passenger cars to learn the business and be trained for position as an engineer. Experienced in drafting, design, layout work and repair. Age 23; unmarried.

0111 YOUNG ENGINEER University graduate with experience in designing, drafting, assembling and testing. Age 23; unmarried. Location no object. Available at once.

0112 SALES ENGINEER College man with broad practical experience and successful record would like to get in touch with progressive automotive organization which has an opening for a man of initiative and ability in that capacity or as service executive.

0113 SALES ENGINEER Graduate mechanical engineer with experience in directing wholesale and retail sales and service departments in automobile business is available for position with sales organization in the same or a similar line of business. Age 30; unmarried.

0114 GRADUATE ENGINEER who has had 10 years' practical experience in designing, production, experimental engineering, drafting and as an executive wishes to make a connection with a progressive firm where a good future is dependent upon work and ability. Available at once. Age 30.

0115 AUTOMOTIVE ENGINEER University graduate with four years' experience in engine assembling, electrical repair work, experimental testing and production. Unmarried. Prefer Eastern location.

0116 PRODUCTION MANAGER or shop superintendent with eight years' experience in experimental, factory cost, planning and modern personnel work. Has had a college education. Age 30; married.

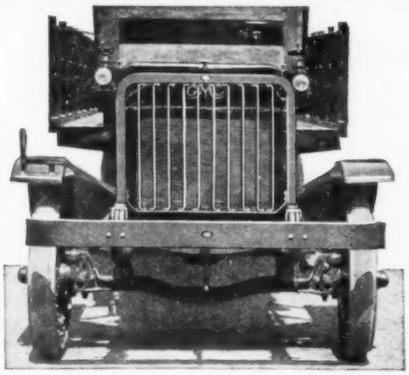
0117 ENGINEER Experienced in accessory and truck design and also in editorial, advertising, publicity, service and sales work. Age 30; married. Available at once.

0118 AUTOMOBILE ENGINEER with 15 years' experience in all lines of automobile engineering. Age 35. Available at once. Prefers to locate in Middle West.

0119 EXPERIMENTAL ENGINEER A keen, energetic, reliable, broadminded man with 20 years' practical experience in various executive capacities covering development, experimental and production work, desires to make a permanent connection with a progressive organization where initiative, ability and energy will be appreciated. Has been asscciated with leading engineers and largest firms in the industry. Can serve in capacities of experimental supervisor, special representative of general manager, superintendent and assistant to chief engineer. Prefer Detroit or Cleveland but would consider any other locality. Age 39; married.

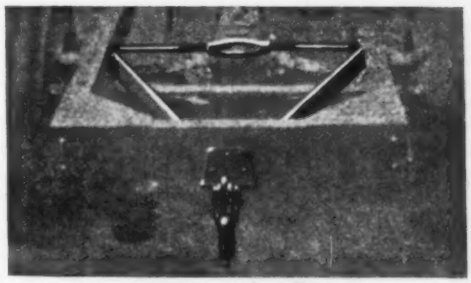
0120 TRANSPORTATION ENGINEER with sales and engineering experience desires to become associated with a company building a quality truck. Is capable of acting as assistant to sales manager. Technical graduate.

(*Continued on page* 62)



Mansfield Type "B" Radiator Guard and Type "I" Front Bumper

have been "Listed as Standard" by Underwriters' Laboratories. Breast drill and wrench are the only tools required to apply any of our equipment.



Type "E" Trailer or Towing Attachment.

MANSFIELD STEEL CORPORATION
954 East Milwaukee Avenue Detroit, Michigan

DOEHLER
DIE-CASTING CO.

WORLD'S LARGEST PRODUCERS OF
DIE-CASTINGS
TIN,-LEAD,-ZINC,-ALUMINUM-ALLOYS.
DO-DI BRASS.

MAIN OFFICE and EASTERN PLANT
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S.HEAD & PROSPECT AVES.

WESTERN PLANT
CHICAGO ILL.
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DISTRIBUTED TO THE TRADE BY
NORTH EAST SERVICE INC.
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ATLANTA DETROIT SAN FRANCISCO
CHICAGO NEW YORK KANSAS CITY
WINDSOR, ONT. CANADA PARIS, FRANCE

SPARTON
MOTORHORNS
First Choice of America's Best Cars
The Sparks-Withington Co.
JACKSON, MICH.
(231)

BROWN-LIPE-GEAR
TRANSMISSIONS
BROWN-LIPE-CHAPIN
DIFFERENTIALS
Both at Syracuse, N.Y.

DRAFTSMEN, ENGINEERS DESIGNERS

Improve your position by familiarizing yourself with up-to-date practice in design and construction of automobile engineering. Become technically trained.

"MOTOR VEHICLE ENGINEERING. ENGINES" (by E. Favary, Consulting Engineer) gives you a TECHNICAL EDUCATION, using only simple mathematics. This book contains the information needed by you to advance yourself; it contains the latest data, detail drawings of the various parts of the best known automobile and truck engines; simple formulae for figuring the strength and dimensions; testing engines. Price, postpaid, $3.50. Send your order to

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MANUFACTURERS of STRIP STEEL HOT and COLD ROLLED

Worcester Pressed Steel Company
WORCESTER, MASSACHUSETTS
Branch Offices
New York Chicago Detroit Indianapolis

GILLIAM
Tapered Roller Bearings

have longer endurance, greater strength, and easier running qualities.

"They last longer Because they are stronger"

THE GILLIAM MFG. CO.
CANTON, OHIO
Detroit Sales Offices: 4829 Woodward Ave.
W. L. Malotte, Manager

POSITIONS AVAILABLE

95 TECHNICAL GRADUATE with sufficient practical experience to qualify as an instructor on any part of an automobile, truck or tractor. Location, New Jersey. Government position.

111 INSTRUCTOR Man with a thorough knowledge of automotive electrical equipment. Must be young and possess ability to handle young men. An ex-service man would fit in well if he had the necessary qualifications

113 BODY HARDWARE MANUFACTURER is in need of a representative to call on automobile trade in Illinois, Wisconsin and Missouri as a side line.

114 SALES AND ADVERTISING MANAGER for a new automatic thermostatic control of electric cooking devices invented by automotive engineer. Operations to be confined to the Middle West for the first year.

116 SALESMEN who have initiative, strong personality and who have been in direct contact with the buying public are desired to sell passenger cars on a commission basis.

*117 DRAFTSMAN with experience in the design of electrical ignition and lighting systems. Man with a thorough knowledge of this work and who can make complete designs to meet special conditions is wanted. Full information should be given in the first letter.

*118 FIRST-CLASS BODY ENGINEER, capable of executing body designs of all descriptions, superintending the construction of sample bodies and writing out complete specifications. Man having experience with body framework and metal laying out; one who is familiar with painting, upholstery and general manufacturing specifications. In other words, a man to assume complete charge of all body engineering of the company. Must have 10 years' experience at least.

*119 INSPECTION ENGINEER One who has had at least 10 years' experience with high-grade engine builders, more especially eight-cylinder V-type engines; an executive who can generally supervise the entire inspection of the building of such engines and is absolutely familiar with the best practice.

120 DESIGNING ENGINEER with A-1 references is desired by a Colorado builder of steam vehicles.

121 MACHINE SHOP FOREMAN for plant building steam cars.

126 INSTRUCTORS IN EXPERIMENTAL ENGINEERING. Graduates in mechanical engineering who have specialized in automobile engineering preferred. Location, Georgia.

127 SALESMAN who is in close touch with automotive engineers is desired, to introduce to the industry several laboratory devices including a high-speed balanced diaphragm type indicator.

130 YOUNG MAN between 25 and 35 to fill a vacancy in the sales and advertising department. Must possess strong personality and be of good character. Experience in sales and engineering work preferable but not essential. No traveling at present but some later on if occasion demands. A good organizer is desired.

133 SALES REPRESENTATIVE wanted by manufacturer of gears for the automotive trade. One who is acquainted with the trade preferred. Salary and commission basis. Headquarters in Detroit. State age, experience and previous connections.

134 ENGINEER for sales development and advertising work is desired by a manufacturer of high-class gears. Salary and commission basis. Headquarters in Boston. State age, experience and previous connections.

(*Concluded on page* 64)

*See announcement at the head of the "Positions and Men Available" column, page 50.

FOUNDRY DEPARTMENT

Even aeroplane manufacturers are using our foundry department more and more. For we are specialists in the casting of

Aluminum, Bearing Metals
Manganese & Phosphor Bronze
& All Non-Ferrous Metals

Let us estimate on your next order.

"Quality" Die Castings

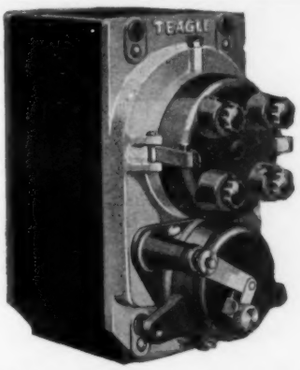
Have you given a try-out yet to "Quality" Die Castings?

Motor and Transmission Department

"Quick on the get-away"—always said of the L. M. F. Motors with exclusive "HOT-SPOT."

We carry out your specifications in making transmissions, gears and other motive parts.

LIGHT MFG. & FOUNDRY CO.
Pottstown, Pa., U. S. A.



SIMPLICITY-RUGGEDNESS
EFFICIENCY-ECONOMY
Always associate these Qualities with

TEAGLE MAGNETO

A BETTER SPARK IN A SIMPLER WAY

Conforms to S. A. E. Standards
THE TEAGLE CO., Cleveland, O.
You want to know more about this *simplest* magneto—write 1128 Oregon Avenue for details.

AICO
COLD MOLDED PARTS

How the Aico Engineering Department Can Reduce the Cost of Your Molded Parts

The Aico method of cold molding electrical parts and automotive units reduces cost and produces work of the finest quality.

Radiator caps produced by the Aico cold molding process carry the maker's personal guarantee that they will not warp, crack or change in color. Aico caps are not affected by heat or anti-freeze mixtures.

Our Engineering Department is operated for the use of all consumers of cold molded insulations, and we will welcome an opportunity of discussing your molding problems and offering possible suggestions for more practical production designs with resultant reduction in molding costs.

American Insulator Corp., New Freedom, Pa.
Chicago Office: 564-570 West Monroe Street.
Detroit Office: 836-840 Cherry Street.
Montreal Office: 103 Notre Dame Street, W.
New York Office: 120 Broadway.

DEALERS EVERYWHERE

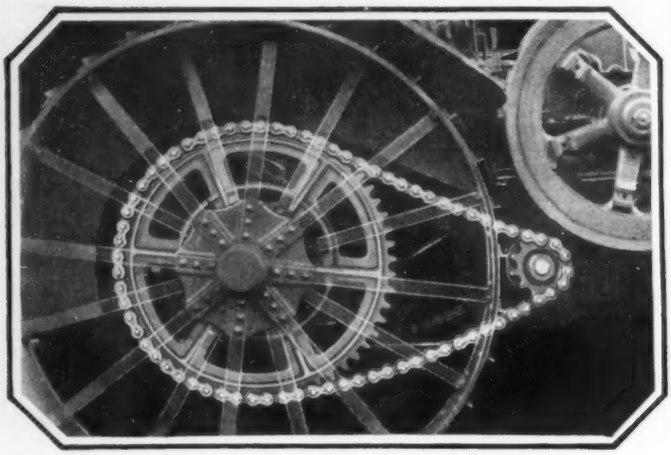
are reaping a harvest of Big Profits selling the MARKO STORAGE BATTERY—First in exclusive features—First in salability—Last to wear out

FIRST!-
Because They Outlast All Others

Pin this in Your Memory!

All Standard MARKO BATTERIES have heavier positive and correspondingly thinner negative plates assuring a more evenly balanced element which absolutely prevents buckling and greatly increases the life of the battery.

PAUL M. MARKO & CO., INC.
Main Office and Works
1402-1412 Atlantic Ave., Brooklyn, N. Y.



Baldwin Chain Drive Used on the I H C "Titan" Tractor

In the Farm Implement Field—

Long ago, Baldwin chain drives made their mark in the farm implement field. Since that time, their almost universal use by leading implement manufacturers— as a final drive on their tractors and in many and varied applications on implements— has been a lasting testimonial of their unfailing dependability and their long, carefree life.

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Cincinnati, Ohio	Wirthlin-Mann Co., 318-320 West Third St.
Cleveland, Ohio	Chain & Sprocket Service Co., 1794 East 55th St.
Detroit, Mich.	Baldwin Service Co., 8641 Woodward Ave.
Kansas City, Mo.	Motor & Machinists Supply Co., 1617 Grand Ave.
Kansas City, Mo.	The Faeth Company, 1117-1131 W. Eighth St.
Los Angeles, Calif.	Colyear Motor Sales Co., 1222-1228 South Hill St.
Minneapolis, Minn.	Baldwin Service Co., 39 South 11th Street
New Orleans, La.	M. H. Rykoski, 706-708 Julia St.
New York City	C. D. Schmidt Co., 276 Canal St.
Philadelphia, Pa.	N. A. Petry Co., Inc., 328-334 North Randolph St.
Portland, Oregon	H. W. Sharp Co., 68-70 First Street
Providence, R. I.	Lanphear Motor Car Co., 17 Snow St.
San Francisco, Calif.	The Adam-Hill Co., 96 Ninth St.
Seattle, Wash.	Wade & Co., 1423 Twelfth Ave.
St. Paul, Minn.	C. J. Smith Co., 155 W. Fifth St.
St. Louis, Mo.	American Automobile & Supply Co., 3200 Locust St.
Montreal, Toronto, Winnipeg, Can.	Lyman Tube & Supply Co., Limited

BALDWIN CHAIN & MFG. CO.
WORCESTER, MASS.

H. V. GREENWOOD, *Western Sales Representative*
PEOPLES GAS BUILDING, CHICAGO, ILLINOIS

GENUINE BALDWIN CHAINS

POSITIONS AVAILABLE
Concluded

135 RESEARCH ENGINEER to take charge of lubrication department of Government laboratory at Washington.

136 EXPERIMENTAL ENGINEER to take charge of exhaustive tests of tractors under state law and also conduct experimental and research work on farm machinery.

137 GENERAL MANAGER who is capable of reorganizing and operating an automobile plant producing a car of the high-grade medium price class. Must have wide experience and reputation with some good firm.

138 SHOP SUPERINTENDENT or production man for a high-grade brass plant employing at present 110 people. Must be familiar with modern shop practice and a real producer. Located in a Michigan town of about 5000 people, 100 miles from Detroit.

139 INSTRUCTOR to take charge of automotive school opening July 1. Technical training, executive and promoting ability, and some actual work as a mechanic desirable. Location, Toledo.

140 SALES ENGINEER Manufacturer of electrical equipment requires traveling sales engineer to sell product to manufacturers of high-grade automobiles and gasoline engines. Unusual opportunity for first-class man having broad selling experience.

141 FACTORY OR PRODUCTION MANAGER for automobile plant getting ready to produce 3000 cars per year. Location Pennsylvania.

142 SHOP SUPERINTENDENT to take active charge of a gear manufacturing shop. Sales experience essential. A man able to secure business, make quotations and direct the production is desired.

143 ENGINEER wanted to take charge of experimental department of a Middle West automobile, truck and tractor plant.

144 ENGINEER experienced in gear design, manufacture and research desired by a Detroit automobile builder.

145 TRANSPORTATION ENGINEER is desired by Middle West truck company. Duties will be the collection of data covering competitive trucks, accessories and equipment; and engineering questions. Will do some traveling making surveys of various territories from the vocational standpoint.

146 ENGINEER who is experienced in ignition work. Drafting experience essential. Good opportunity for advancement. Location Pennsylvania.

147 ENGINEER with unusual experience and knowledge of wheels to assist in the development, research work and testing of a new steel wheel.

GENERAL DROP FORGE CO.
SPECIAL DROP FORGINGS OF ALL KINDS TO ORDER
SEND US PRINTS OR MODELS FOR PRICES
BUFFALO, N. Y.

A Complete Line of Quality

LEATHER H L B

Fan Belts and Parts

"Weltprufe" Flat Fan Belting.
Vee Lug Fan Belting.
Vee Sol, "V" Fan Belting.
Vee Flex, "V" Fan Belting.
Fan Belts for all Motor Vehicles.

Leathertex Cone Clutch Facings.
Disc Clutch Facings.
Anti-Squeak Frame Padding.
Leather Tire Straps and Cut Lacings.
Discs, Boots, Gaskets, Washers, etc.

Write for Catalog and Prices.

Hide Leather & Belting Co. Indianapolis

COUNTER BALANCED CRANK SHAFTS

MADE BY

The PARK DROP FORGE CO.
CLEVELAND, OHIO

Quality Predominates

The big reason why so many Gilmer products are used by automotive manufacturers lies in the fact that every Gilmer product is *basically* constructed to overcome every obstacle to superior service. That is why over 80% of the cars made in America are factory equipped with Gilmer Woven Endless Fan Belts.

The following Gilmer Woven Products are widely used as regular equipment.

Woven Endless Fan Belts
Body, Spring and Radiator Shims
Radiator and Hood Lacing
Transmission Lining
Rebound Straps
Top, Tire and Door-check Straps
Strainer Web
Webbing for all purposes

L. H. GILMER CO.
Philadelphia, Pa.

Gilmer WOVEN PRODUCTS

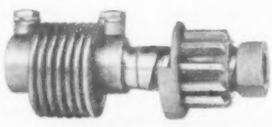
KELLOGG TIRE PUMPS

KELLOGG MANUFACTURING COMPANY, ROCHESTER, N. Y., U. S. A.

G & O Radiators

THE G & O MANUFACTURING CO.
NEW HAVEN CONN.

BENDIX ECLIPSE DRIVE
for ELECTRIC STARTERS



AUTOMATIC ENGAGING & DISENGAGING

194 Motor Car and Truck Builders Use It

ECLIPSE MACHINE CO.
ELMIRA N.Y.

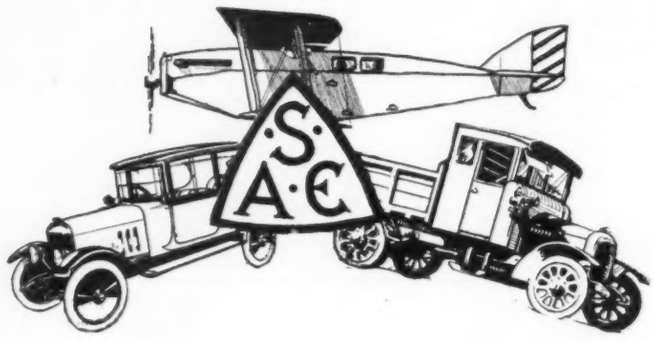
ACME-DIE

·CASTINGS·

ALUMINUM·ZINC·TIN & LEAD ALLOYS

Acme Die-Casting Corp.

Boston Rochester Brooklyn N.Y. Detroit Chicago



The Circulation of This Issue of the Journal Is 6500

Does your advertising manager appreciate that the men who read the JOURNAL hold responsible positions in the industry in the following classes:

Chief Engineers	**Tool Engineers**
Staff Engineers	**Executive Officers**
Consulting Engineers	**Service Engineers**
Production Engineers	**Designers**
Factory Managers	**Draftsmen**

Purchasing Agents

You know that you read the JOURNAL with unusual interest and depend upon its advertising section to keep you acquainted with the newest developments in the industrial field. If you are engaged in producing material that is sold to men in the automotive field, you must realize the effectiveness of advertising in the JOURNAL.

Maybe your company's advertising is not included in this month's advertising section, and we generally find that this is because your advertising manager may not only be unfamiliar with the existence of the JOURNAL, but he even may not know of the S. A. E. and the important position it has in the industry. Show him this number and suggest that he write to our advertising department for information as to rates, etc.

REDMANOL

Perfect Moulded Insulation

It excels in

Heat Resistance
Dielectric Strength
Mechanical Strength
Acid Resistance
Accuracy of Dimensions

Redmanol Chemical Products Co.
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STEEL TOOL FRASSTEELS ALLOY

For Immediate Delivery

S. A. E. STEELS

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Inquiries Solicited

Manufacturers
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American Hammered Piston Ring Co.
BALTIMORE, MD.
EXPORT DEPT., 461 EIGHTH AVE., NEW YORK, N. Y.

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Mr. Producer and Designer

Besides the protection from theft, Karlok carries with it a 15% reduction on theft insurance premiums. This will prove an inducement to prospective buyers of your car.

Write for particulars.

Karlok Manufacturing Co.
Newark, N. J.

Raybestos MOLDED CLUTCH FACING
PATENTED—GUARANTEED

THE RAYBESTOS COMPANY

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Bridgeport, Conn.; Peterborough, Ont., Can.

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CHICAGO	332 South Michigan Ave.
SAN FRANCISCO	1403 Chronicle Building
WASHINGTON, D. C.	107 Columbian Building

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USE CROFOOT GEARS

Users of Crofoot Gears are getting the extra power that is usually wasted when ordinary gears are used. Crofoot Gears are made with such microscopic accuracy that all avoidable friction is entirely eliminated. Result: more power, less noise.

Made in all types and sizes and in any quantity.

Screw machine work up to 5" diameter. Precision grinding of every description up to 6" diameter for external work and up to 5" diameter for internal work.

Spurs
Bevels
Mitres
Spirals
Helicals
Worms
Worm
Gears

AGMA
Member American Gear Manufacturers' Association

Crofoot Gear Works, Inc.
Hyde Park Ave., at Readville
BOSTON, 37, MASS.

SHEET METAL STAMPING

We are building axle housings, brake drums, and other parts for the heaviest motor trucks ever built, and have ample capacity for still heavier.

With our complete equipment we cover the entire sheet metal stamping line.

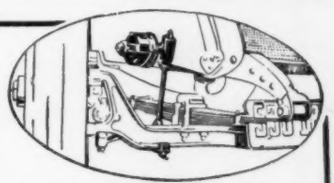
We solicit your inquiries.

THE CROSBY COMPANY

DETROIT OFFICE: 914 Ford Bldg. BUFFALO, N. Y. CLEVELAND OFFICE: 415 Schofield Bldg.
New York Office: 30 Church Street

COMFORT

Houdaille Hydraulic
(*say Hoo-dye*)
Shock Absorbers



GIVE absolute comfort to every car. Prevent body sway, spring breakage; check rebound.

Houdailles are standard equipment on leading European cars, such as Delage, Minerva, Panhard, Pic-Pic, Peugot, Rochet-Schneider, etc., also American Cunningham and new Duesenberg Straight 8.

THE HOUDAILLE CO.
1435 Root Bldg. Buffalo, N. Y.

INDEX TO ADVERTISERS' PRODUCTS

Absorbers, Shock
Houdaille Co.

Alloys, Special Non-Ferrous
Haynes Stellite Co.

Ammeters
Nagel Electric Co., W. G.

Axle-Housings, Pressed Steel
Hydraulic Pressed Steel Co.
Ireland & Matthews Mfg. Co.
Motor Wheel Corporation
Parish Mfg. Corporation
Parish & Bingham Corporation
Smith Corporation, A. O.

Axles, Front and Rear
Jefferson Forge Products Co.
Park Drop Forge Co
Timken-Detroit Axle Co.
Williams, J. H., & Co.
Wyman-Gordon Co.

Balancing Machines
Olsen Testing Machine Co., Tinius
Vibration Specialty Co.

Balls, Composition, Control Lever
American Insulator Corporation

Balls, Steel
Auburn Ball Bearing Co.
New Departure Mfg. Co.
S K F Industries, Inc.

Barrels, Steel
Hydraulic Pressed Steel Co.

Bars, Bronze Cored
American Bronze Corporation

Bars, Iron and Steel
Interstate Iron & Steel Co.

Batteries, Storage
Marko & Co., Inc., Paul M.
Willard Storage Battery Co.

Battery Parts
Marko & Co., Inc., Paul M.

Beams, Channels and Angles
Interstate Iron & Steel Co.

Bearing Metal, Babbitt
Muzzy-Lyon Co.

Bearing Metal, Bronze
American Bronze Corporation

Bearings, Babbitt
American Bearing & Die Casting Corporation

Bearings, Babbitt and Bronze
American Bearing & Die Casting Corporation
Doehler Die-Casting Co.
Muzzy-Lyon Co.

Bearings, Ball, Angular Contact Type
Gurney Ball Bearing Co.
New Departure Mfg. Co
U. S. Ball Bearing Mfg. Co.

Bearings, Ball, Annular
Fafnir Bearing Co.
Federal Bearings Co.
Gurney Ball Bearing Co.
New Departure Mfg. Co.
S K F Industries, Inc.
U. S. Ball Bearing Mfg. Co.

Bearings, Ball, Annular, Separable (Open) Type
Fafnir Bearing Co.
New Departure Mfg. Co.
Norma Co. of America

Bearings, Ball, Annular, Wide Type
New Departure Mfg. Co.

Bearings, Ball, Thrust
Bantam Ball Bearings Co.
Bearings Co. of America.
Fafnir Bearing Co.
Norma Co. of America.
S K F Industries, Inc.
U. S. Ball Bearing Mfg. Co.

Bearings, Bronze
American Bearing & Die Casting Corporation
American Bronze Corporation

Bearings, Graphite and Bronze
American Bearing & Die Casting Corporation
Bound Brook Oil-less Bearing Co.
Muzzy-Lyon Co.

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Bearings, Oilless
Bound Brook Oil-less Bearing Co.

Bearings, Roller
Bower Roller Bearing Co.
Gilliam Mfg. Co.
Hyatt Roller Bearing Co.
Spicer Mfg. Corporation
Timken Roller Bearing Co.

Bells or Gongs, Mechanical
New Departure Mfg. Co.

Belting, Fan
Gilmer Co., L. H
Goodrich Rubber Co., B. F.
Hide Leather & Belting Co.

Belting, Silent Chain
Link-Belt Co.
Morse Chain Co.
Whitney Mfg. Co.

Blanks, Gear
American Manganese Bronze Co.
Central Steel Co.

Bodies, Automobile, Closed
Baker R & L Co.

Bolts, Chassis
Steel Products Co.

Bolts, Coupling
Steel Products Co.

Brackets, Fender
Parish Mfg. Corporation

Brackets, Running Board
Parish Mfg. Corporation

Brake Rod Assemblies
Steel Products Co.

Brakes
Raybestos Co.

Bumpers, Protective
Mansfield Steel Corporation

Bumpers, Rubber
Thermoid Rubber Co.

Bushings, Babbitt
American Bearing & Die Casting Corporation
Muzzy-Lyon Co.

Bushings, Bronze
American Bearing & Die Casting Corporation
American Bronze Corporation
American Manganese Bronze Co.

Bushings, Graphite & Bronze
Bound Brook Oil-less Bearing Co.

Bushings, Oilless
Bound Brook Oil-less Bearing Co.

Cable Assemblies
Packard Electric Co.

Cable, Ignition, Starting and Lighting
Kerite Insulated Wire and Cable Co.
Packard Electric Co.
Rome Wire Co.

Cables Armored
Packard Electric Co.

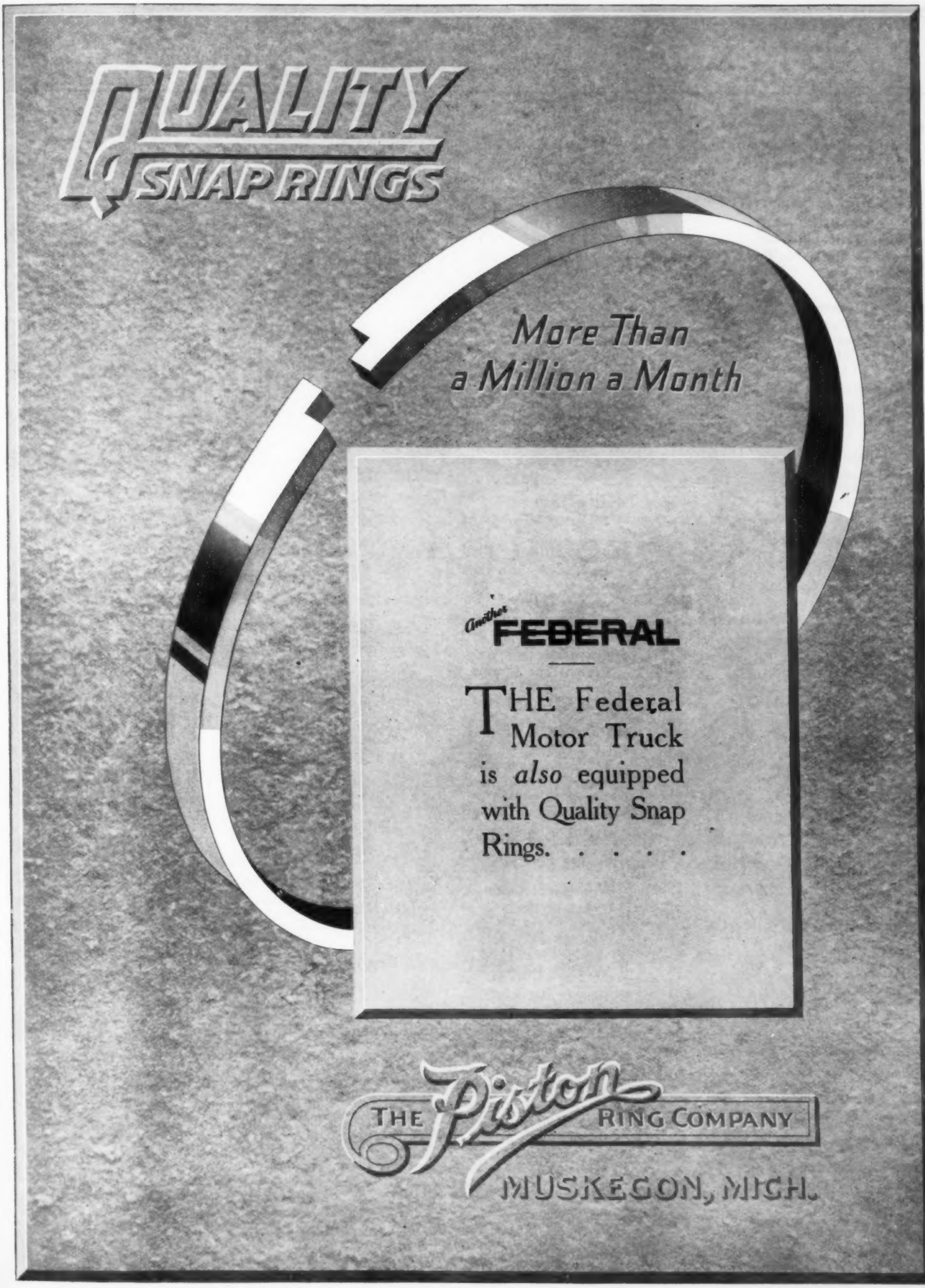
Camshafts
Jefferson Forge Products Co.
Muskegon Motor Specialties Co.
Wyman-Gordon Co.

Caps, Hub
Ireland & Matthews Mfg. Co.

Caps, Radiator
American Insulator Corporation
Redmanol Chemical Products Co.

Castings, Aluminum, Brass and Bronze
Acme Die-Casting Corporation
American Bronze Corporation
American Manganese Bronze Co.
Doehler Die-Casting Co.
Light Mfg. & Foundry Co.

The Index to Advertisers is given on pages 76 and 78


QUALITY
SNAP RINGS
More Than
a Million a Month
Another FEDERAL
THE Federal
Motor Truck
is also equipped
with Quality Snap
Rings. . . . .
THE Piston RING COMPANY
MUSKEGON, MICH.

INDEX TO ADVERTISERS' PRODUCTS

Castings, Die
Acme Die-Casting Corporation
American Bearing & Die Casting Corporation
Doehler Die-Casting Co.
Light Mfg. & Foundry Co.

Castings, Malleable Iron
American Malleable Castings Assn.
Link-Belt Co.

Chains, Automobile Engine
Link-Belt Co.
Morse Chain Co.
Whitney Mfg. Co.

Chains, Block
Morse Chain Co.
Whitney Mfg. Co.

Chains, Silent
Link-Belt Co.
Morse Chain Co.
Whitney Mfg. Co.

Chains, Sprocket Wheel
Link-Belt Co.
Morse Chain Co.
Whitney Mfg. Co.

Chains, Transmission or Driving
Baldwin Chain & Mfg. Co.
Link-Belt Co.
Morse Chain Co.

Channels, Pressed Steel
Parish Mfg. Corporation

Chucks, Quick Change
Whitney Mfg. Co.

Clamps, Hose
Schrader's Son, Inc., A

Clamps, Machinists'
Williams, J. H., & Co.

Cleats, Fiber
American Vulcanized Fibre Co.

Clutches
Covert Gear Co.
Fuller & Sons Mfg. Co.
Hartford Automotive Parts Co.
Link-Belt Co.

Coils, Field
Acme Wire Co.

Collars, Ball Bearing
Bantam Ball Bearing Co.

Connecting-Rods
Jefferson Forge Products Co.
Williams, J. H., & Co.

Connections, Tire Pump
Schrader's Son, Inc., A.

Cooling Systems
G & O Mfg. Co.
Long Mfg. Co.
United States Cartridge Co.

Couplings, Flexible
Thermoid Rubber Co.

Cranes, Portable Electric
Baker R & L Co.

Cranks, Starting
Steel Products Co.

Crankshafts
Jefferson Forge Products Co.
Park Drop Forge Co.
Williams, J. H., & Co.
Wyman-Gordon Co.

Cutters, End Mill
Haynes Stellite Co.

Cutters, Keyway
Whitney Mfg. Co.

Cutters, Milling
Haynes Stellite Co.

Dashes
Parish Mfg. Corporation

Differentials
Brown-Lipe Chapin Co.
New Process Gear Corporation
Ross Gear & Tool Co.

Discs, Clutch
Hide Leather & Belting Co.
Thermoid Rubber Co.

Discs, Steel Clutch
Motor Wheel Corporation

Drive, Electric Motor
Eclipse Machine Co.

Drives, Silent Chain
Link-Belt Co.
Morse Chain Co.
Whitney Mfg. Co.

Drop Forgings (See Forgings, Drop)

Drums, Brake
Motor Wheel Corporation
Parish Mfg. Corporation

Drums, Pressed Steel Brake
Crosby Co.
Hydraulic Pressed Steel Co.
Ireland & Matthews Mfg. Co.
Motor Wheel Corporation
Parish & Bingham Corporation

Dynamic and Static Balancing
Vibration Specialty Co.

Engines, Marine
Wisconsin Motor Mfg. Co.

Engines, Passenger-Car
Weidely Motors Co.
Wisconsin Motor Mfg. Co.

Engines, Tractor
Light Mfg. & Foundry Co.
Weidely Motors Co.
Wisconsin Motor Mfg. Co.

Engines, Truck
Continental Motors Corporation
Light Mfg. & Foundry Co.
Weidely Motors Co.
Wisconsin Motor Mfg. Co.

Facings, Clutch
Johns-Manville, Inc.
Thermoid Rubber Co.

Fenders
Parish Mfg. Corporation

Fiber, Vulcanized
American Vulcanized Fibre Co.

Flanges, Pressed Steel Hub
Motor Wheel Corporation

Forgings, Bronze
American Manganese Bronze Co.

Forgings, Drop
Bearings Co. of America
General Drop Forge Co.
Jefferson Forge Products Co.
Smith Corporation, A. O.
Spicer Mfg. Corporation
Williams, J. H., & Co.
Wyman-Gordon Co.

Foundry Equipment
Standard Pattern Works of Detroit, Inc.

Frames, Molybdenum Steel Automobile
Parish Mfg. Corporation

Frames, Pressed Steel
Hydraulic Pressed Steel Co.
Parish & Bingham Corporation
Smith Corporation, A. O.

Fuel Feed Systems
Ireland & Matthews Mfg. Co.

Fuses, Automobile Lighting,
Johns-Manville, Inc.

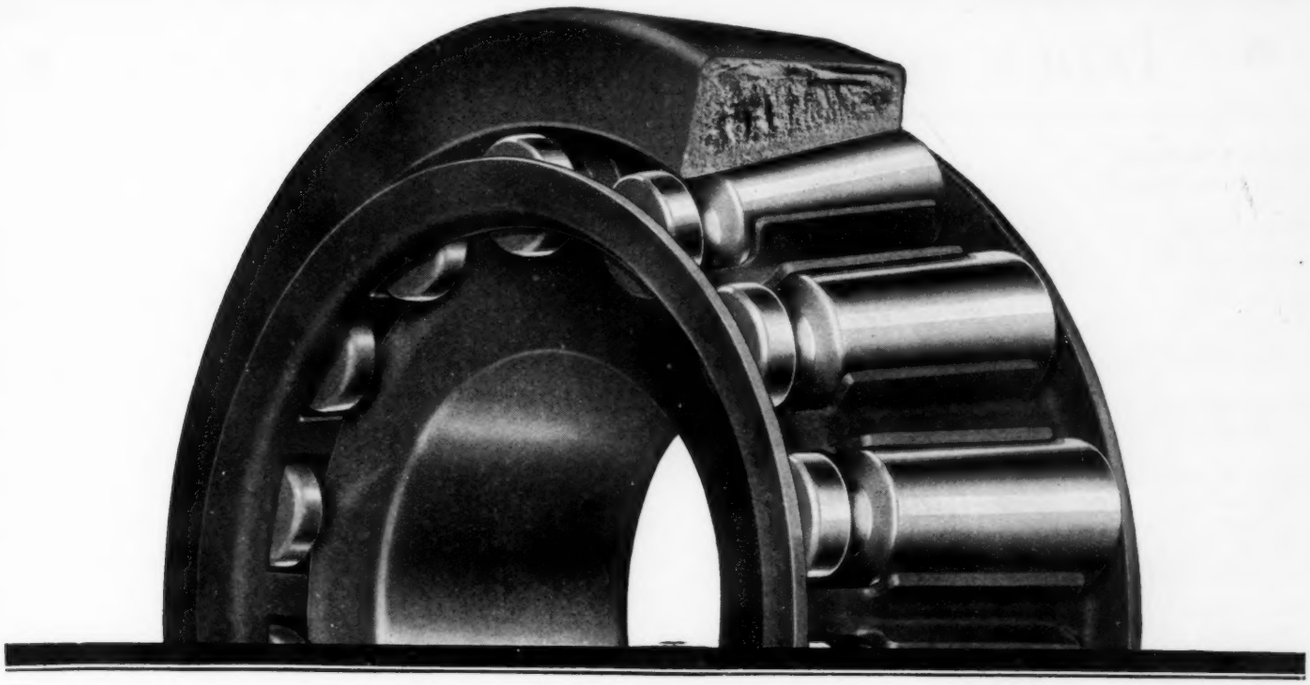
Gages, Tire Pressure
Schrader's Son, Inc., A.

Gaskets, Fiber
American Vulcanized Fibre Co.

Gasoline
Texas Co.

Gears, Bevel
Crofoot Gear Works, Inc.
Link-Belt Co.
New Process Gear Corporation

The Index to Advertisers is given on pages 76 and 78



Sound Engineering

That the Timken principle of adjustability is sound engineering is attested to by general engineering practice throughout every motor driven vehicle.

In all the important working parts about a motor vehicle that are subject to wear from motion, adjustment is uniformly provided.

Bronze bushings are placed in the spring eyes; shims are used in the main bearings of the motor; tapered adjustment is provided in the steering gear; take-up for wear resulting from motion is engineered into the clutch, into the brakes, in the cam shaft mounting; and even such parts as carburetor, valves, carburetor springs, ignition devices, etc, are all provided for adjustment or take-up for that wear which *must* follow motion.

It is not surprising that designing engineers should be responsible for the use of more than fifty-seven million Timken Tapered Roller Bearings in 422 American and European passenger cars, trucks, tractors, and trailers.

The Timken Roller Bearing Co, Canton, O

Timken Tapered Roller Bearings for Passenger Cars, Trucks, Tractors, Trailers, Farm Implements, Machinery, and Industrial Appliances

TIMKEN
Tapered
ROLLER BEARINGS

INDEX TO ADVERTISERS' PRODUCTS

Gears, Differential
Jefferson Forge Products Co.

Gears, Miter
Link-Belt Co.

Gears, Spur
Crofoot Gear Works, Inc.
Link-Belt Co.
New Process Gear Corporation

Gears, Steering
Ross Gear & Tool Co.

Gears, Transmission
Brown-Lipe Gear Co.
Jefferson Forge Products Co.
Morse Chain Co.
Wyman-Gordon Co.

Gears, Worm
Link-Belt Co.
New Process Gear Corporation

Generators, Battery Charging (for Electric Vehicles
North East Electric Co.

Generators, Ignition and Lighting
North East Electric Co.

Graphite
Dixon Crucible Co., Jos.

Greases, Cup and Gear
Dixon Crucible Co., Jos.
Texas Co.

Guards, Radiator
Mansfield Steel Corporation

Guns, Grease
Ireland & Matthews Mfg. Co.

Hangers, Pressed Steel Step
Hydraulic Pressed Steel Co.
Motor Wheel Corporation
Parish & Bingham Corporation

Heaters, Car Body
Perfection Heater & Mfg. Co.

Heaters, Mixture
Master Primer Co.

Horns, Automobile
E. A. Laboratories, Inc.
North East Electric Co.
Sparks-Withington Co.

Hose, Gasoline
Thermoid Rubber Co.

Hose, Radiator
Thermoid Rubber Co.

Hubs, Motor Vehicle
Motor Wheel Corporation

Hydraulic Suspension
Houdaille Co.

Ignition Apparatus
Atwater Kent Mfg. Co.
North East Electric Co.
Packard Electric Co.

Instruments, Measuring and Testing
Norma Co. of America

Insulation, Molded
American Insulator Corporation
General Bakelite Co.

Jars, Battery, Rubber
Goodrich Rubber Co., B. F.

Joints, Universal
Hartford Automotive Parts Co.
Spicer Mfg. Corporation
Thermoid Rubber Co.

Keys, Woodruff
Whitney Mfg. Co.

Laboratory Apparatus and Supplies
Olsen Testing Machine Co., Tinius

Levers, Transmission
Jefferson Forge Products Co.

Linings, Brake
Johns-Manville, Inc.
Raybestos Co.
Thermoid Rubber Co.

Linings, Frame
Gilmer Co., L. H.

Links, Drag
Steel Products Co.

Locks, Automobile
Karlok Mfg. Co.

Locomotives, Industrial, Electric
Baker R & L Co.

Lubricants
Dixon Crucible Co., Jos.
Texas Co.

Lubricating Systems
Ireland & Matthews Mfg. Co.

Lubricators
Madison-Kipp Corporation

Magnetos
Teagle Co.

Molded Machine Equipment
Standard Pattern Works of Detroit, Inc.

Motors, Gasoline. (See Engines.)

Motors, Starting. (See Starters, Electric Engine.)

Nails
Interstate Iron & Steel Co.

Oil Cups
Madison-Kipp Corporation

Oilers, Mechanical
Madison-Kipp Corporation

Oils, Lubricating
Texas Co.

Paints
Dixon Crucible Co., Jos.

Patterns, Wood and Metal
Standard Pattern Works of Detroit, Inc.

Pins, Piston
Steel Products Co.

Power Take-off
Fuller & Sons Mfg. Co.

Pistons
Seymour Laboratoried Units, Inc.

Power Transmission Machinery
Link-Belt Co.
Morse Chain Co.
Whitney Mfg. Co.

Primers, Engine
Master Primer Co.

Propeller-Shaft Assemblies
Hartford Automotive Parts Co.
Spicer Mfg. Corporation

Publications
Motor

Pumps, Air
Kellogg Mfg. Co.

Pumps, Oil
Madison-Kipp Corporation

Pumps, Tire
Kellogg Mfg. Co.

Radiators
G & O Mfg. Co.
Long Mfg. Co.
Modine Mfg. Co.
Sparks-Withington Co.
United States Cartridge Co.

Retainers, Ball
Bearings Co. of America.

Rims, Pneumatic Tire
Motor Wheel Corporation

Rings, Piston
American Hammered Piston Ring Co.
Ever Tyte Piston Ring Division
Gill Mfg. Co.
Piston Ring Co.
Seymour Laboratoried Units, Inc.

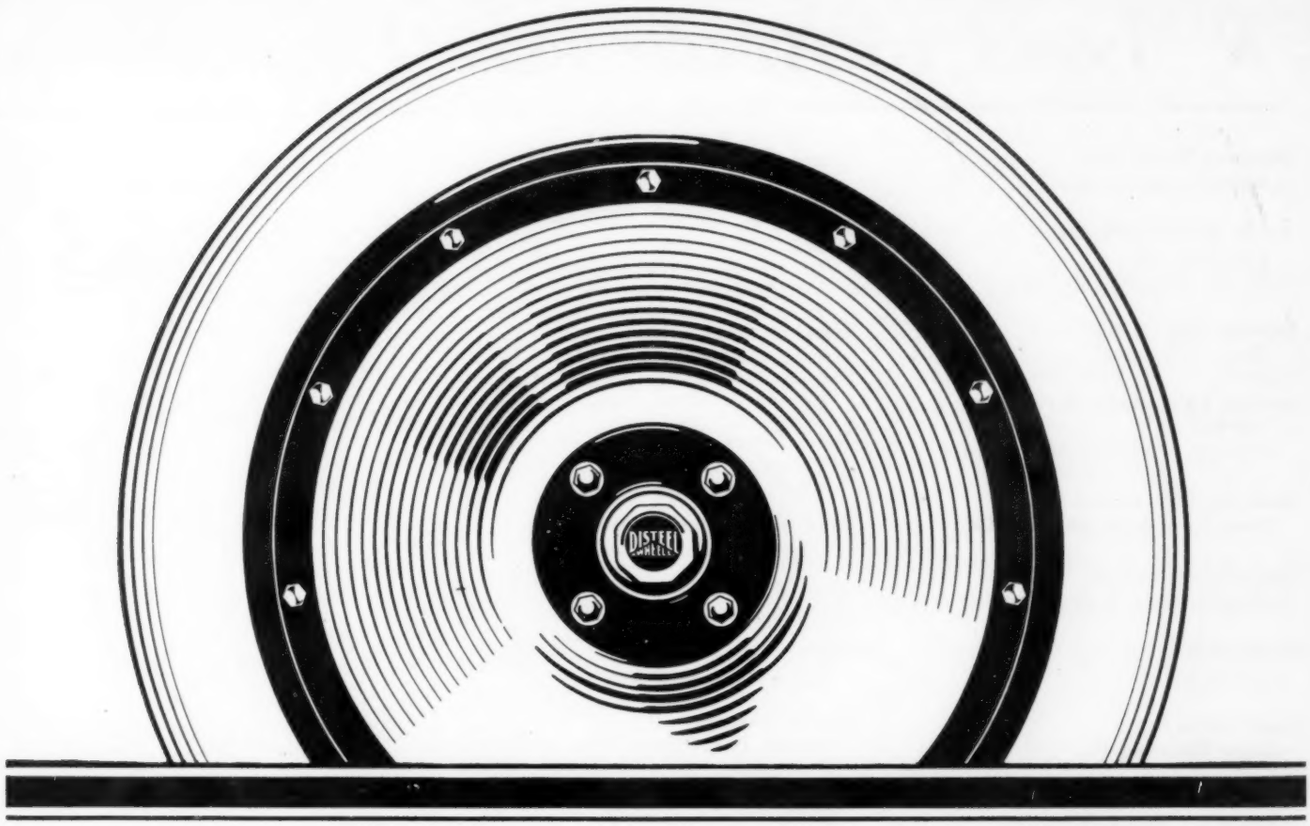
Rivets
Interstate Iron & Steel Co.
Ireland & Matthews Mfg. Co.

Rods, Fiber
American Vulcanized Fibre Co.

Roller Bearings. (See Bearings, Roller.)

Running Boards
Parish Mfg. Corporation

The Index to Advertisers is given on pages 76 and 78



One of our friends has described Disteel Wheels as spokeless and speechless. He is right. They are wheels that never "talk back."

If you have experienced the annoyance of squeaking, rattling motor car wheels you will appreciate this Disteel advantage immediately. Like soup and children wheels should be seen but not heard.

Exclusive Manufacturers: **Detroit Pressed Steel Company**

New York Boston **DISTEEL WHEEL CORPORATION** Chicago San Francisco

DETROIT, U. S. A.

DISTEEL WHEELS

INDEX TO ADVERTISERS' PRODUCTS

Scrapers, Steel Billet
Haynes Stellite Co.

Screw Machine Products
Link-Belt Co.
Spicer Mfg. Corporation

Screws, Cap
Steel Products Co.

Service, Laboratory on Piston Rings and Valves
Seymour Laboratoried Units, Inc.

Shafting, Cold Drawn
Columbia Steel & Shafting Co.

Shapes, Cold Drawn
Columbia Steel & Shafting Co.

Shims, Bearing
Laminated Shim Co., Inc.

Speedometers
Johns-Manville, Inc.

Sprockets
Baldwin Chain & Mfg. Co.
Link-Belt Co.
Morse Chain Co.

Stampings
Crosby Co.
Hydraulic Pressed Steel Co.
Ireland & Matthews Mfg. Co.
Motor Wheel Corporation
Parish Mfg. Corporation
Parish & Bingham Corporation
Smith Corporation, A. O.
Spicer Mfg. Corporation
Worcester Pressed Steel Co.

Starters, Electric Engine
North East Electric Co.

Starting, Automatic Meshing Drive for
Eclipse Machine Co.

Steel, Alloy
Central Steel Co.
Columbia Steel & Shafting Co.
Frasse & Co., Inc., Peter A.
Interstate Iron & Steel Co.

Steel, Axle
Central Steel Co.

Steel, Bessemer and Open-Hearth
Columbia Steel & Shafting Co.

Steel, Bright Finished
Union Drawn Steel Co.

Steel, Chrome
Central Steel Co.
Interstate Iron & Steel Co.

Steel, Chrome Nickel
Central Steel Co.
Interstate Iron & Steel Co.

Steel, Cold Drawn
Columbia Steel & Shafting Co.
Union Drawn Steel Co.

Steel, Nickel
Central Steel Co.
Columbia Steel & Shafting Co.
Interstate Iron & Steel Co.

Steel, Screw
Columbia Steel & Shafting Co.
Union Drawn Steel Co.

Steel, Silico-Manganese
Interstate Iron & Steel Co.

Steel, Strip
Worcester Pressed Steel Co.

Tacks
Interstate Iron & Steel Co.

Tanks, Vacuum
Ireland & Matthews Mfg. Co.

Testing Machines
Olsen Testing Machine Co., Tinius

Tires, Pneumatic
Goodrich Rubber Co., B. F.

Tires, Solid
Goodrich Rubber Co., B. F.

Tool Holders
Williams, J. H., & Co.

Tools, Welded
Haynes Stellite Co.

Torsion-Rod Assemblies
Steel Products Co.

Tractors, Electric
Baker R & L Co.

Trailer Attachment
Mansfield Steel Corporation

Transformers
Packard Electric Co.

Transmissions
Brown-Lipe Gear Co.
Covert Gear Co.
Fuller & Sons Mfg. Co.
Link-Belt Co.
Morse Chain Co.

Trucks, Elevating, Electric
Baker R & L Co.

Trucks, Industrial, Electric
Baker R & L Co.

Tubes, Inner
Goodrich Rubber Co., B. F.

Tubing, Brass
United States Cartridge Co.

Tubing, Copper
United States Cartridge Co.

Tubing, Fiber
American Vulcanized Fibre Co.

Tubing, Rubber
Thermoid Rubber Co.

Tubing, Steel
Frasse & Co., Inc., Peter A.
Smith Corporation, A. O.

Valves, Poppet
Rich Tool Co.
Seymour Labor .toried Units, Inc.
Steel Products Co.

Valves, Tire
Schrader's Son, Inc., A.

Voltmeters
Nagel Electric Co., W. G.

Washers, Fiber
American Vulcanized Fibre Co.

Washers, Graphite & Bronze
Bound Brook Oil-less Bearing Co.

Washers, Oil-less
Bound Brook Oil-less Bearing Co.

Washers, Special
Ireland & Matthews Mfg. Co.

Welding, Electric
Steel Products Co.

Welding Outfits, Oxy-acetylene
Steel Products Co.

Wheels, Motor Truck
Automotive Wood Wheel Mfrs. Ass'n
Motor Wheel Corporation

Wheels, Passenger Car
Jefferson Forge Products Co.
Motor Wheel Corporation

Wheels, Sprocket
Link-Belt Co.
Whitney Mfg. Co.

Wire and Cable, Insulated
Rome Wire Co.

Wire, Enamel Covered
Acme Wire Co.

Wire, Magnet
Acme Wire Co.

Wire, Silk and Cotton Covered
Acme Wire Co.

Wrenches
Williams, J. H., & Co.

The Index to Advertisers is given on pages 76 and 78

What Counts in Producing Frames

Equipped with Hydraulic Frame

The quality of steel and the character of workmanship are of fundamental importance in producing *good* frames.

Hydraulic rolls its own steel and builds frames in its own plant. From furnace to finished product all operations are under Hydraulic control. Hydraulic *knows* that the high standard of quality for steel *is* maintained.

The men look upon their work as not merely a task to be completed, but a service to be performed. They take pride in accomplishment. They have an interest in their work. Care, thought and skill are combined into a high order of workmanship, which is reflected in the splendid service which *every* Hydraulic Frame renders.

THE HYDRAULIC PRESSED STEEL COMPANY
of THE HYDRAULIC STEEL COMPANY
CLEVELAND, OHIO

Manufacturers of

Pressed Steel Frames for Passenger Cars, Trucks and Tractors; Axle Housings; Brake Drums; Torque Arms; Running Boards; Step Hangers; Hub Flanges; Discs; Dust Shields; Steel Barrels; Aeroplane and Miscellaneous Stampings.

Branch Sales Offices

New York
Singer Building

Chicago
Fisher Building

Detroit
Book Building

HYDRAULIC
FRAMES

INDEX TO ADVERTISERS

A

Acme Die-Casting Corporation 65
Acme Wire Co..... 54
American Bearing & Die-Casting Corporation..... 58
American Bronze Corporation Inside front cover
American Hammered Piston Ring Co. 67
American Insulator Corporation 63
American Lead Pencil Co.. 57
American Malleable Castings Assn. 35
American Manganese Bronze Co. 59
American Vulcanized Fibre Co. 51
Atwater Kent Mfg. Co..... 8
Automotive Wood Wheel Mfrs.' Assn. 38

B

Bakelite Co. (General)..... 23
Baker R & L Co..... 26
Baldwin Chain & Mfg. Co... 64
Bantam Ball Bearing Co... 57
Bearings Co. of America... 48
Bound Brook Oil-less Bearing Co. 60
Bower Roller Bearing Co... 33
Brown-Lipe-Chapin Co. & Brown-Lipe Gear Co..... 61

C

Central Steel Co..... 41
Columbia Steel & Shafting Co. 49
Continental Motors Corporation 36
Cooper Union Book Store... 62
Covert Gear Co., Inc..... 6
Crofoot Gear Works, Inc... 67
Crosby Co. 67

D

Disteel Wheel Corporation.. 73
Dixon Crucible Co., Joseph. 3
Doehler Die-Casting Co.... 61

E

E. A. Laboratories, Inc..... 59
Eaton Axle Co..... 10
Eclipse Machine Co..... 65
Ever-Tyte Piston Ring Division 4

F

Fafnir Bearing Co..... 12
Federal Bearings Co., Inc.. 51
Frasse & Co., Inc., Peter A.. 67
Fuller & Sons Mfg. Co..... 46

G

G & O Mfg. Co..... 65
General Bakelite Co..... 23
General Drop Forge Co.... 64
Gill Mfg. Co..... 65
Gilliam Mfg. Co..... 62
Gilmer Co., L. H..... 65
Goodrich Co., B. F..... 53
Gurney Ball Bearing Co.... 49

H

Hartford Automotive Parts Co. 46
Haynes Stellite Co..... 9
Hide Leather & Belting Co.. 65
Houdaille Co. 67
Hyatt Roller Bearing Co... 25
Hydraulic Pressed Steel Co.. 75

I

Interstate Iron & Steel Co.. 78
Ireland & Matthews Mfg. Co. 45

J

Jefferson Forge Products Co. 21
Johns-Manville, Inc. 53

K

Karlok Mfg. Co..... 67
Kellogg Mfg. Co..... 65
Kerite Insulated Wire & Cable Co. 1

L

Laminated Shim Co., Inc... 47
Light Mfg. & Foundry Co.. 63
Link-Belt Co. 29
Long Mfg. Co..... 77

M

Madison-Kipp Corporation.. 17
Mansfield Steel Corporation. 61
Marko & Co., Inc., Paul M... 63
Master Primer Co..... 11
Members' Professional Cards 42, 43
Men Available 50
Modine Mfg. Co..... 19
Morse Chain Co..... 20
Motor 5
Motor Wheel Corporation... 22
Muskegon Motor Specialties Co. 55
Muzzy-Lyon Co. 27

N

Nagel Electric Co., W. G.... 59
New Departure Mfg. Co.... 56
New Process Gear Corporation 51
Norma Co. of Americca.... 50
North East Electric Co.... 61

O

Olsen Testing Machine Co., Tinius.....Inside back cover

The Index to Advertisers' Products is given on pages 68, 70, 72 and 74

Whether used on motor cars, trucks or tractors, Long Cooling Systems assure continuous service, uninterrupted by any radiation trouble.

Our Engineering Department Can Assist You

Each Long Cooling System is designed to order for each type of motor with which it is to be used. Each step in creating the design is taken in co-operation between the Engineering Departments of our factory and those of the manufacturer. Proper design insures proper construction. By reason of this co-operation, Long Cooling Systems represent minimum cost and maximum efficiency.

Let us confer with you regarding your radiation problems.

LONG MANUFACTURING CO., DETROIT, MICHIGAN

Pioneer Makers of Cooling Systems for Gasoline Engines

LONG
COOLING SYSTEMS

The Recognized Standard for Tractors, Trucks and Motor Cars

INDEX TO ADVERTISERS

P

Packard Electric Co..... 44
Parish & Bingham Corporation 44
Parish Mfg. Corporation... 28
Park Drop Forge Co..... 65
Perfection Heater & Mfg. Co. 31
Piston Ring Co..... 69
Positions Available..... 62

R

Raybestos Co. 67
Redmanol Chemical Products Co. 67
Rich Tool Co..... 40
Rome Wire Co..... 2
Ross Gear & Tool Co..... 14

S

S K F Industries, Inc..... 18
Schrader's Sons, Inc., A.... 55
Seymour Laboratoried Units, Inc..... 13
Sharon Pressed Steel Co.... 79
Smith Corporation, A. O.... 48
Sparks-Withington Co..... 61
Spicer Mfg. Corporation.... 52
Standard Pattern Works of Detroit, Inc. 59
Steel Products Co..... 7

T

Teagle Co. 63
Texas Co..... 53
Thermoid Rubber Co....34, 80
Timken-Detroit Axle Co.... 24
Timken Roller Bearing Co.. 71

U

Union Drawn Steel Co..... 57
U. S. Ball Bearing Mfg. Co.. 47
United States Cartridge Co. 30

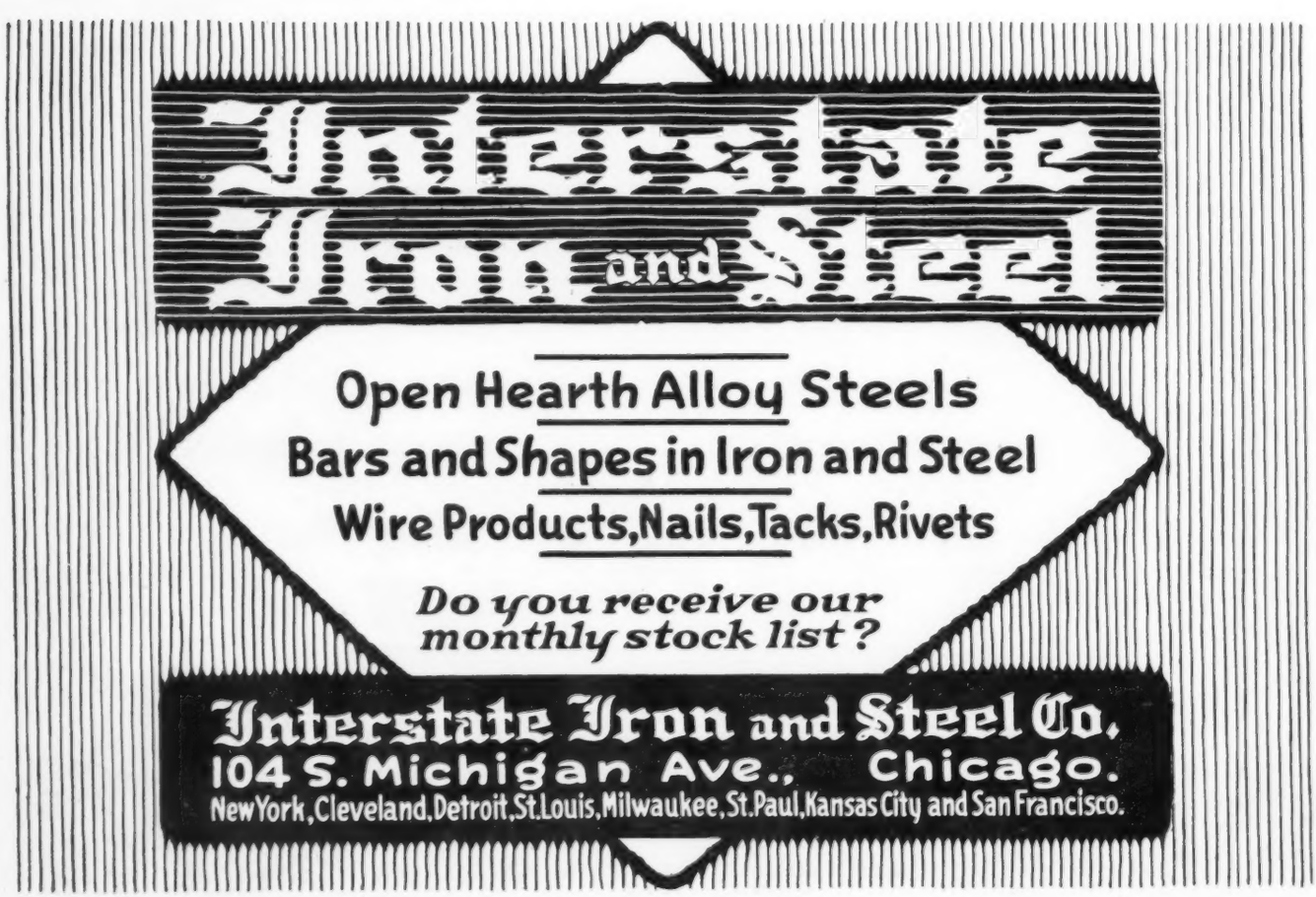
V

Vibration Specialty Co..... 43

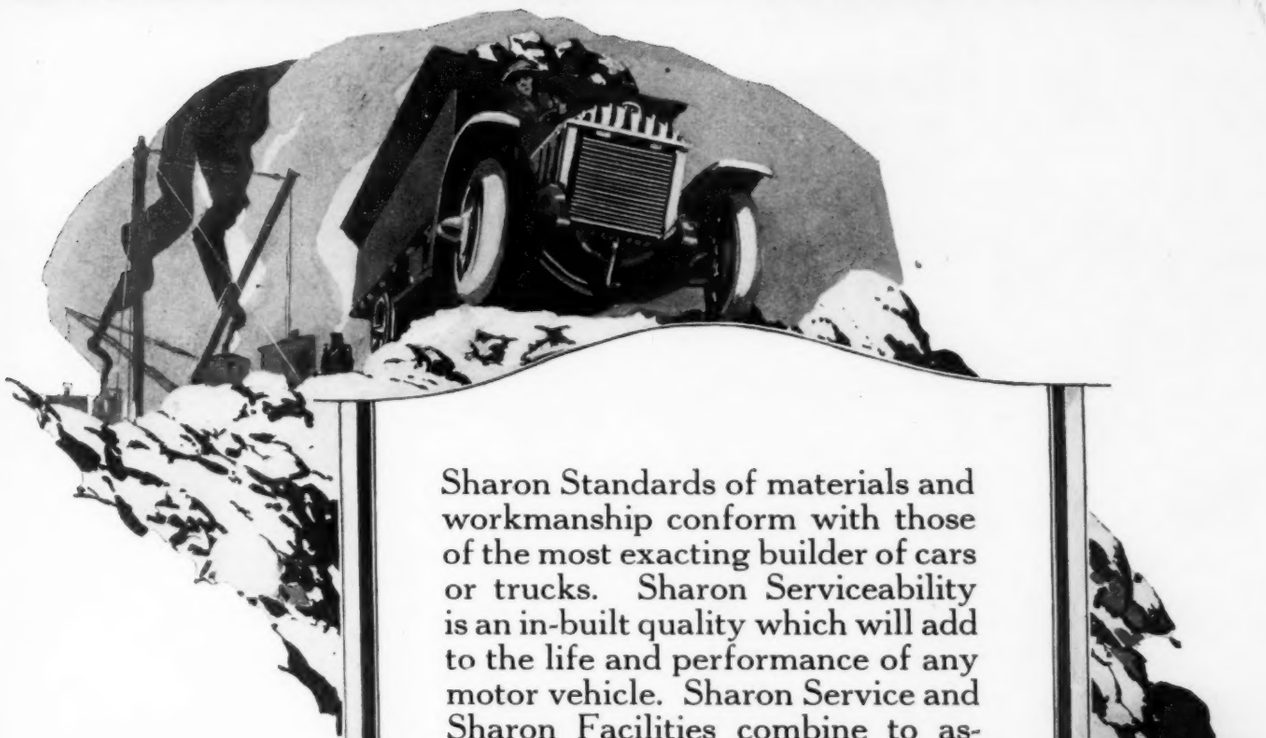
W

Weidely Motors Co..... 57
Westinghouse Electric & Mfg. Co. 37
Whitney Mfg. Co..... 39
Willard Storage Battery Co.. 32
Williams, J. H., & Co..... 55
Wisconsin Motor Mfg. Co. 15, 16
Worcester Pressed Steel Co. 62
Wyman-Gordon Co. Opposite first reading page

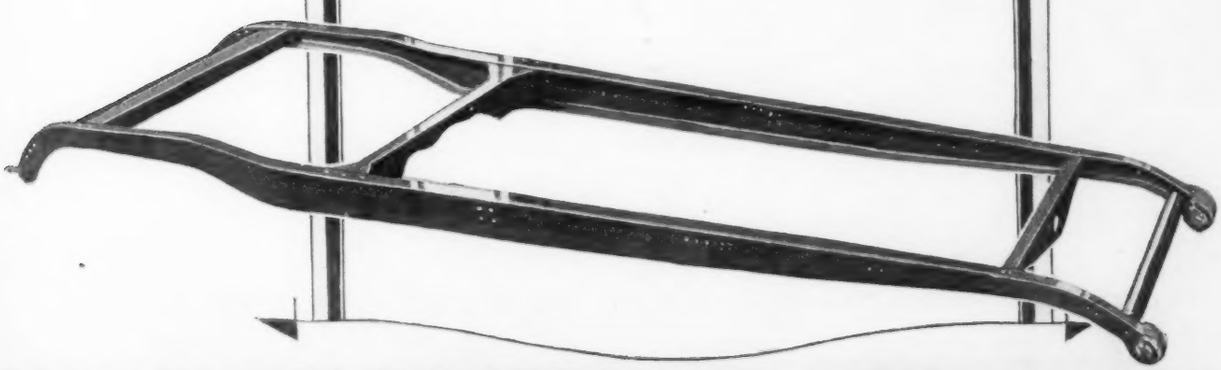
The Index to Advertisers' Products is given on pages 68, 70, 72 and 74


Iron and Steel
Open Hearth Alloy Steels
Bars and Shapes in Iron and Steel
Wire Products, Nails, Tacks, Rivets
Do you receive our monthly stock list?
Interstate Iron and Steel Co.
104 S. Michigan Ave., Chicago.
New York, Cleveland, Detroit, St. Louis, Milwaukee, St. Paul, Kansas City and San Francisco.

SHARON FRAMES

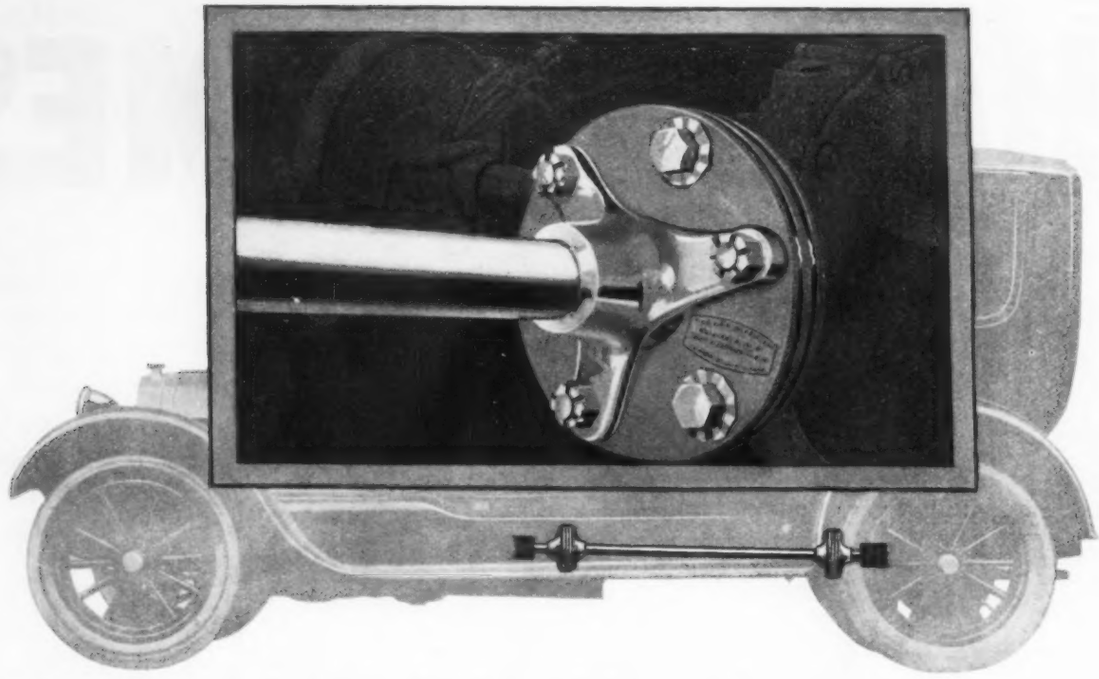


Sharon Standards of materials and workmanship conform with those of the most exacting builder of cars or trucks. Sharon Serviceability is an in-built quality which will add to the life and performance of any motor vehicle. Sharon Service and Sharon Facilities combine to assure unfailing on-time delivery in quantity to meet any production schedule. With increased resources and augmented equipment, we can meet all requirements as to price, quantity and delivery. Send us your specifications. Let our engineers work with yours.



SHARON PRESSED STEEL CO.

MAIN OFFICE AND WORKS, SHARON, PENNA.



Cushioning the twisting blows in the drive shaft

How the flexible Thermoid-Hardy Universal eliminates jolts and jars

YOU throw in the clutch and the whole power of the engine hits the car a sudden blow. This is what happens with metal universal joints. Drive shaft, transmission, rear axle assembly—in all, 15 gears and 12 bearings feel the strain.

Metal joints fail to cushion the blows of starting, of rapidly shifting gears, of going over rough roads. Metal joints soon wear loose, causing rattle and backlash — the danger signal for trouble to follow.

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Fanwise construction for strength

The patented scientific process by which Thermoid-Hardy Universal Joints are constructed is the reason for their great strength and durability. The flexible discs are built up from layers of long strand Sea Island cotton duck and a special friction rubber compound. The layers are arranged fanwise in the well-known Thermoid-Hardy formation, so that the strands of cotton in the various plies run in different directions. The layers are finally welded together under hydraulic pressure until the disc becomes one compact, inseparable mass with a tensile strength of 3,400 pounds per square inch.

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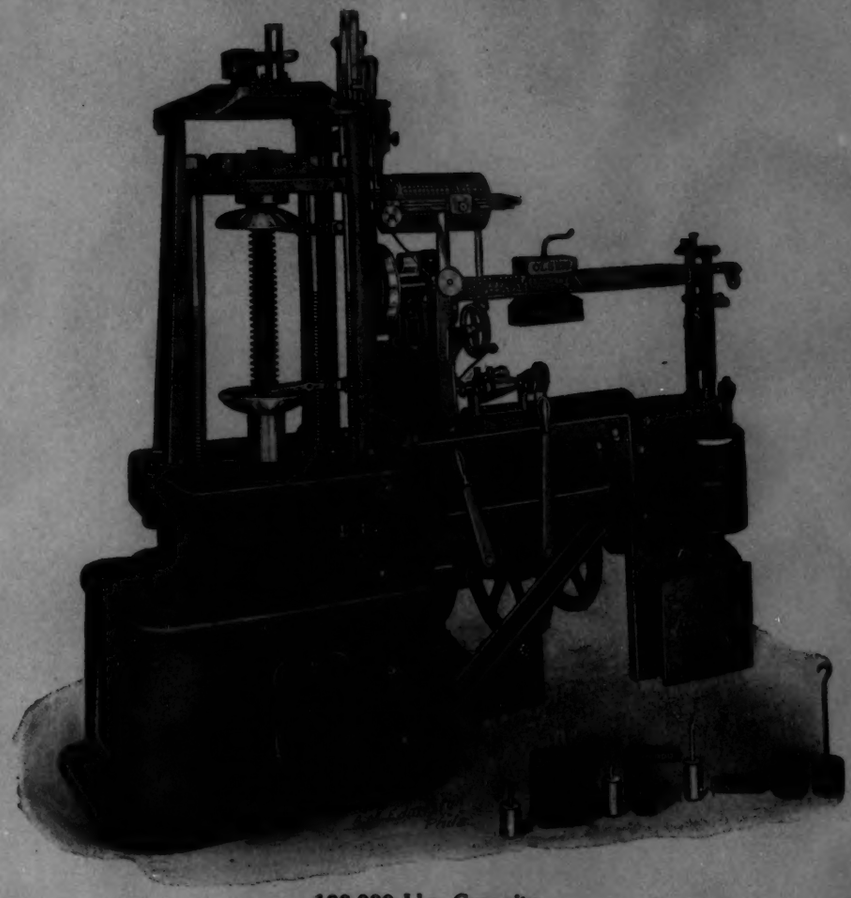

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